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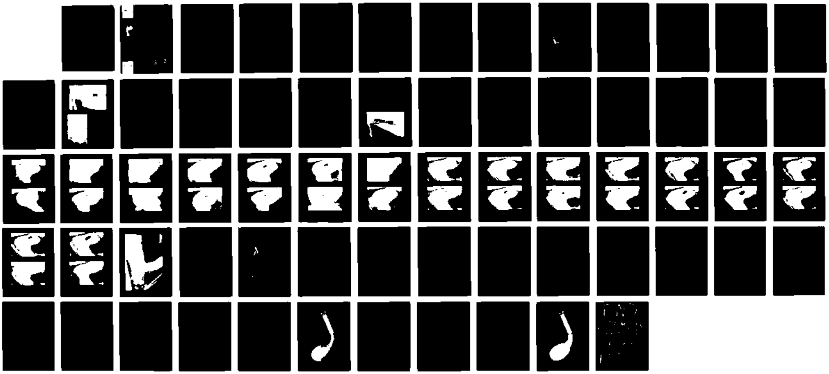

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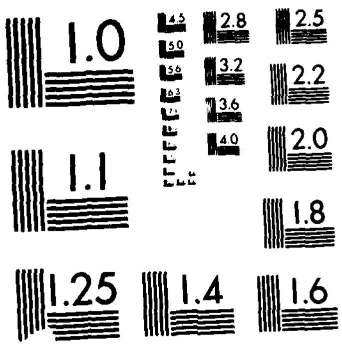

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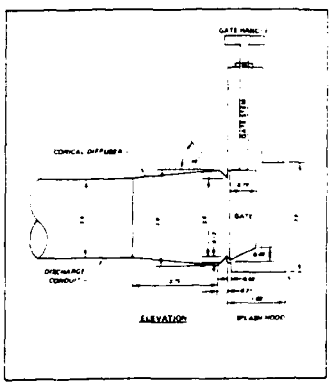

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TECHNICAL REPORT HL-89-7

LITTLE DELL OUTLET STRUCTURE, UTAH

Hydraulic Model Investigation

by

Bobby P. Fletcher

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

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A 1:10-scale physical model of the discharge outlet, plunge pool, and exit channel was used to investigate and develop a practical design that would provide satisfactory hydraulic performance. Operation of the model with the original design indicated satisfactory performance in the conduits and jet flow gates. However, failure of the riprap in the plunge pool and exit channel was observed. The side slopes of the plunge pool and exit channel were modified to provide a stable environment for the riprap.

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PREFACE

The model investigation was authorized by the Headquarters, US Army Corps of Engineers, on 14 September 1987, at the request of the US Army Engineer District, Sacramento. The studies were conducted by personnel of the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES), during the period September 1987 to June 1988 under the direction of Mr. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, and under the general supervision of Messrs. G. A. Pickering, Chief of the Hydraulic Structures Division (HSD), and N. R. Oswalt, Chief of the Spillways and Channels Branch. Project engineer for the model study was Mr. B. P. Fletcher, assisted by Messrs. J. T. Hilbun, J. E. Hall, and J. R. Rucker, Jr., all of HSD. The model was constructed by Mr. W. Landers of the Engineering and Construction Services Division, WES. This report was written by Mr. Fletcher and edited by Mrs. M. C. Gay, Information Technology Laboratory, WES.

During the investigation, Messrs. Royce Cunningham, Harold Huff, and Charles Mifkovic, Sacramento District, visited WES to discuss the program of model tests and observe the model in operation.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

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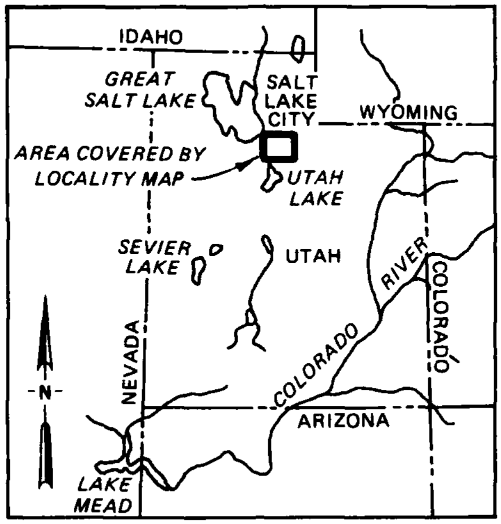
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

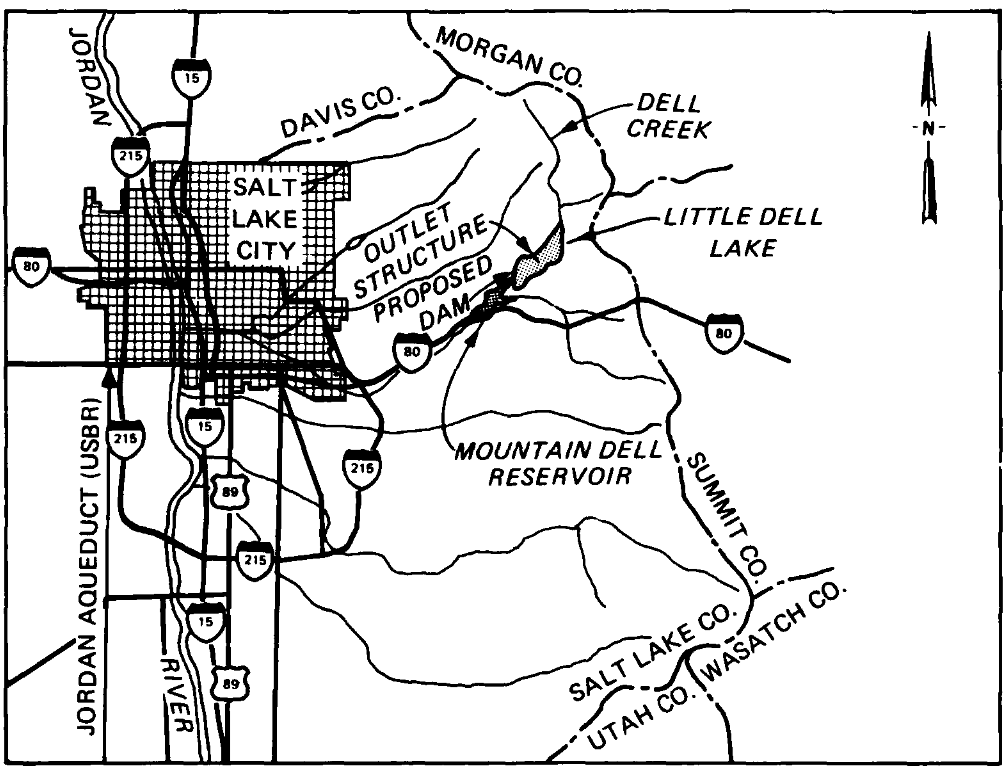
Multiply	By	To Obtain
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre



VICINITY MAP

SCALE

40 0 40 80 MI



LOCATION MAP

SCALE

2 0 2 4 MI

Figure 1. Location and vicinity map

LITTLE DELL OUTLET STRUCTURE, UTAH

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Little Dell Outlet Structure will be located about 8 miles* east of Salt Lake City, UT (Figure 1). The proposed dam will be located on Dell Creek approximately 1.5 miles upstream from the existing Mountain Dell reservoir.

2. The project plan (Plate 1) provides for a rolled earth-fill dam embankment on Dell Creek to impound a 20,500-acre-ft reservoir. An ungated and unlined emergency spillway will be located on the right abutment. The outlet works will consist of a curved tunnel through the left abutment incorporating a midtunnel emergency control chamber located upstream of the dam axis. Operational control will be provided in the operational control structure located at the downstream tunnel portal. A plunge pool will dissipate the energy of released water, which will be returned to Dell Creek. A plan and profile of the recommended project and a plan of the operational control structure are shown in Plates 2 and 3, respectively.

3. The outlet works will have the multiple functions of (a) controlling flood-control and water quality releases from Little Dell Lake, and (b) conveying diverted waters from the Parleys Creek Diversion pipeline into Little Dell Lake. During flood-control operation, the 24-in.-diam water quality conduit and the 42-in.-diam Parleys Creek Diversion pipeline will normally be isolated from the 42-in.-diam flood-control conduit by closing valves located on these pipelines. Only reservoir releases through the flood-control conduit will be possible under these conditions. To make releases through the water quality system, the isolation valve on the flood-control conduit will be closed as well as the separation valve on the Parleys Creek Diversion pipeline. The valve on the water quality conduit will be opened and releases will

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

be made through the water quality conduit and the jet flow control gates. For diversion of Parleys Creek flows into Little Dell Lake, the 42-in. valves on the Parleys Creek Diversion pipeline and on the flood-control conduit will be opened. The valve on the water quality conduit will be closed. The jet flow control gates will be opened only enough to make small releases required downstream of the project. Parleys Creek Diversion flows exceeding downstream release requirements will be conveyed upstream through the outlet works conduit into Little Dell Lake. Once the release requirements exceed the diversion flow, the Parleys Creek Diversion pipeline will be shut. Schematic diagrams of the outlet works components are shown in Figure 2.

4. The outlet works (Plate 2) located through the left abutment will consist of a short approach channel, a submerged concrete intake structure, 320 ft of 6-ft-diam circular cut-and-cover concrete conduit, 340 ft of 6-ft-diam circular tunnel, an 84-ft-long emergency control chamber, 1,230 ft of 42-in.-diam steel conduit housed in a 9.5-ft-diam modified circular tunnel adit, bifurcations to two 36-in.-diam steel conduits each transitioning to a 30-in. diameter and having a 30-in.-diam emergency ball valve and 30-in.-diam jet flow gate for controlling releases, and a 20-ft-deep preformed plunge pool.

5. Outlet works releases will be controlled using jet flow gates. Two 30-in.-diam. jet flow gates will be located at the outlet of each 30-in.-diam steel conduit (Plate 3). The jet flow gates will have a design discharge of 370 cfs and discharge directly to the atmosphere. The fundamental features of the jet flow gates are a truncated conical nozzle, a floating seal ring that forms a circular discharge orifice at the downstream end of the nozzle, and a flat-bottomed gate leaf that contacts and slides across the seal ring orifice to regulate discharges. The basic features produce a contracted, jet-type discharge from the gate resulting in a discharge coefficient of approximately 0.83 at full gate openings and reduced cavitation potential. Jet flow gates were selected over other types of control gates or valves because of the jet flow gates' superior performance under winter icing conditions, low fabrication cost, and cavitation-free operation. A 30-in.-diam full port ball valve will be located approximately 15 ft upstream of each jet flow gate. These ball valves will serve as guard valves for the jet flow gates and will be operated only in the full open or full closed position.

6. The outlet works conduit will terminate with the 30-in.-diam jet

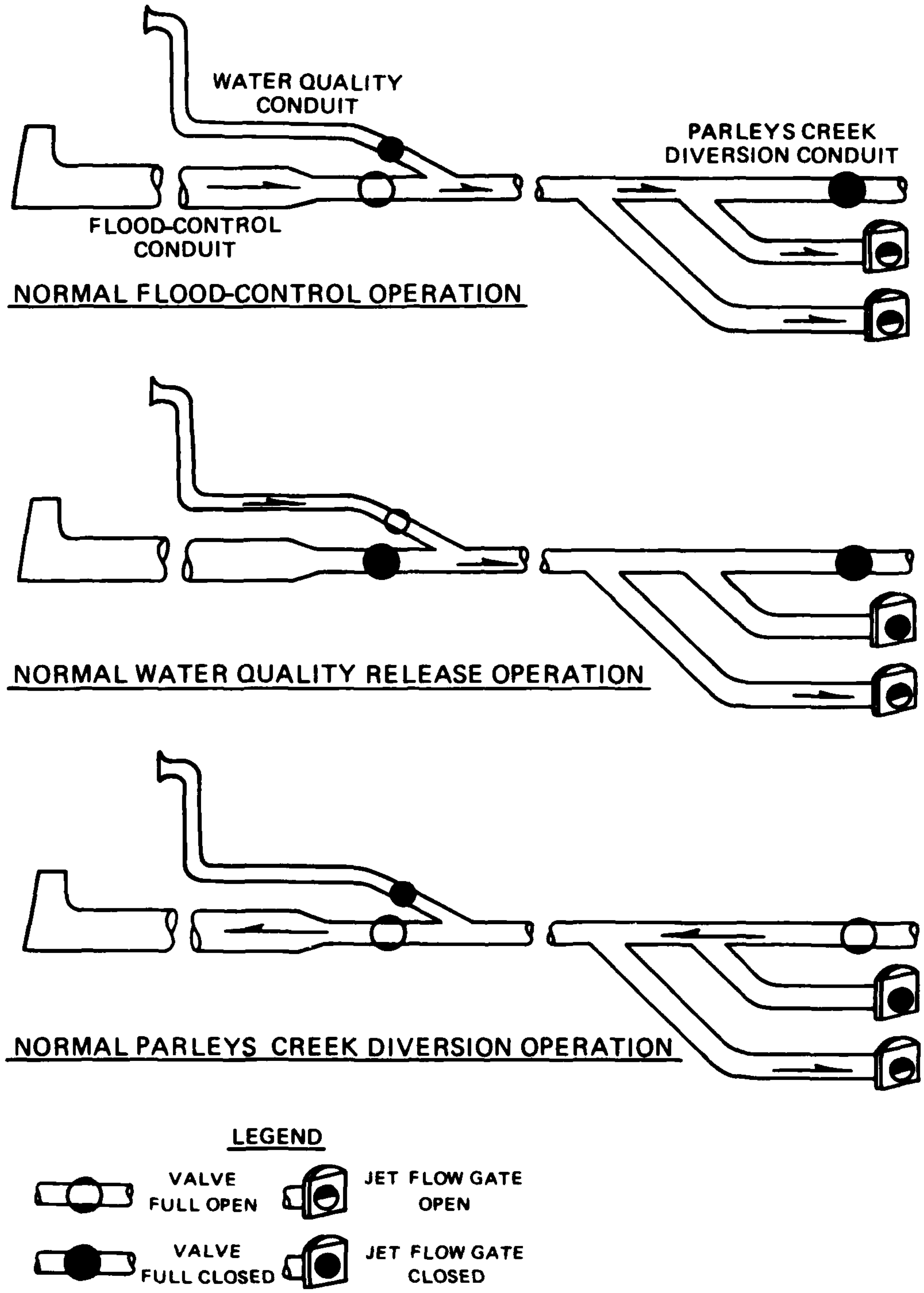

Figure 2. Normal gate and valve operation

flow control gates. Outlet works releases will discharge directly to the atmosphere immediately downstream of the gate orifice. The center-line elevation of the jet flow gates will be 5,575.0.* A short section of steel pipe will function as a hood or deflector for spray at partial gate openings. The discharge jet will be fully aerated downstream of the jet flow gate. Outlet works releases will exit the jet flow gates in a semicylindrical form and will fall in approximately parabolic paths into a preformed plunge pool.

7. Outlet works releases will return to Dell Creek downstream of the plunge pool via an excavated trapezoidal exit channel. The channel will have an 8-ft bottom width and side slopes of 1V on 2H. The channel invert will intersect the plunge pool at el 5,558.5. The exit channel will be approximately 275 ft long with a bottom slope of 0.0060. The channel invert and side slopes will be protected with a layer of rock riprap 18 in. thick. The exit channel will have subcritical flow for the entire range of expected discharges. Where the exit channel intersects the natural streambed, the flow regime will change from subcritical to supercritical. A terminal structure, consisting of 10 ft of concrete-lined channel with cutoff walls, will be provided to prevent head cutting and excessive erosion.

Purpose and Scope of Model Study

8. The model study was conducted to evaluate the potential for cavitation in the discharge conduits, the hydraulic characteristics of the plunge pool and exit channel, and the size and extent of riprap required for protection of the plunge pool and exit channel, and to develop practical modifications required (if needed) for a satisfactory design.

9. Tests were conducted in the 1:10-scale model to evaluate single and multiple gate operation for various anticipated flow conditions.

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

PART II: THE MODEL

Description

10. The model of the Little Dell outlet works (Figures 3 and 4), constructed to a scale ratio of 1:10, included 60 ft of the 3.5-ft-diam conduit upstream of the bifurcation, the bifurcation, the conduits to the jet flow gates, the jet flow gates, the plunge pool, a 300-ft length of the exit channel, and the terminal structure at the downstream end of the exit channel.

11. The conduits and jet flow gates were constructed of transparent plastic to permit observation of dye injected into the flow. Piezometers were installed in the conduits to permit measurement of pressures at critical locations. The plunge pool and exit channel were molded with graded riprap to simulate prototype riprap construction. The terminal structure at the downstream end of the exit channel was constructed of plywood.

12. Water used in operation of the models was supplied by pumps, and discharges were measured by orifice meters.

Interpretation of Model Results

13. The accepted equations of hydraulic similitude based upon Froude criteria were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the model scale or length ratio L_r are presented in the following tabulation:

Dimension	Ratio	Scale Relations Model:Prototype
Length	$L_r = L_r$	1:10
Area	$A_r = L_r^2$	1:100
Velocity	$V_r = L_r^{1/2}$	1:3.16
Time	$T_r = L_r^{1/2}$	1:3.16
Discharge	$Q_r = L_r^{5/2}$	1:316.2
Pressure	$P_r = L_r$	1:10
Weight	$W_r = L_r^3$	1:1,000

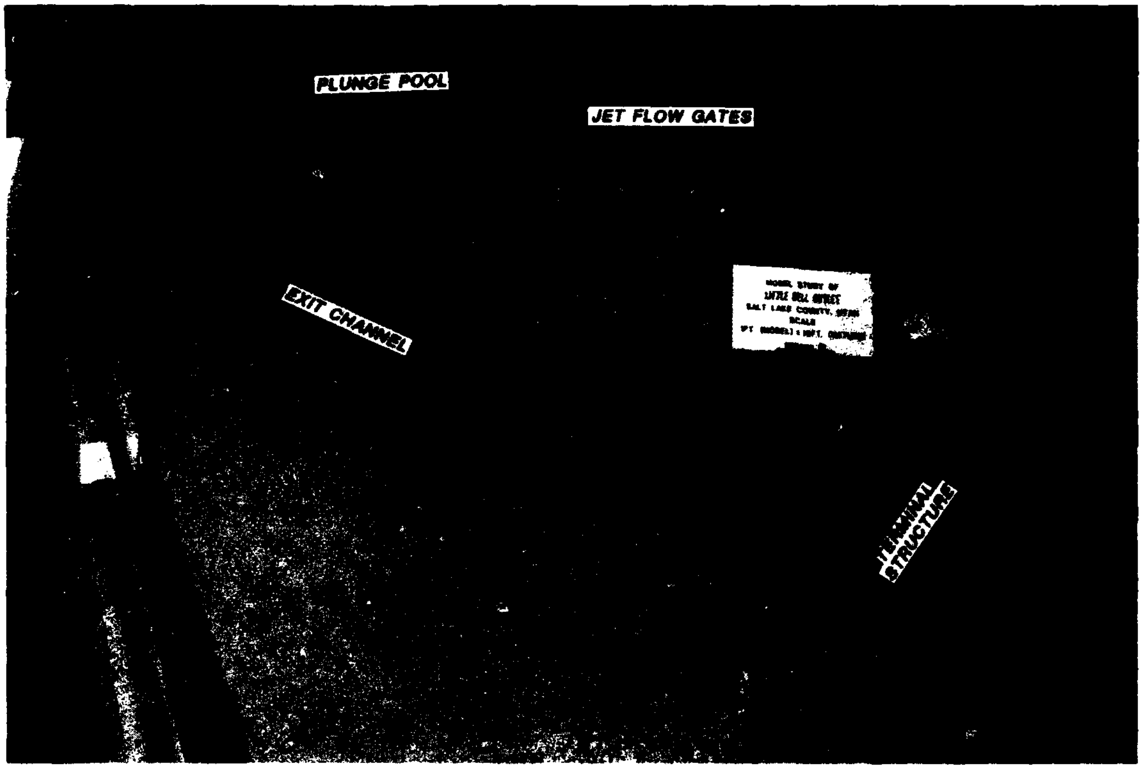


Figure 3. Plunge pool and exit channel

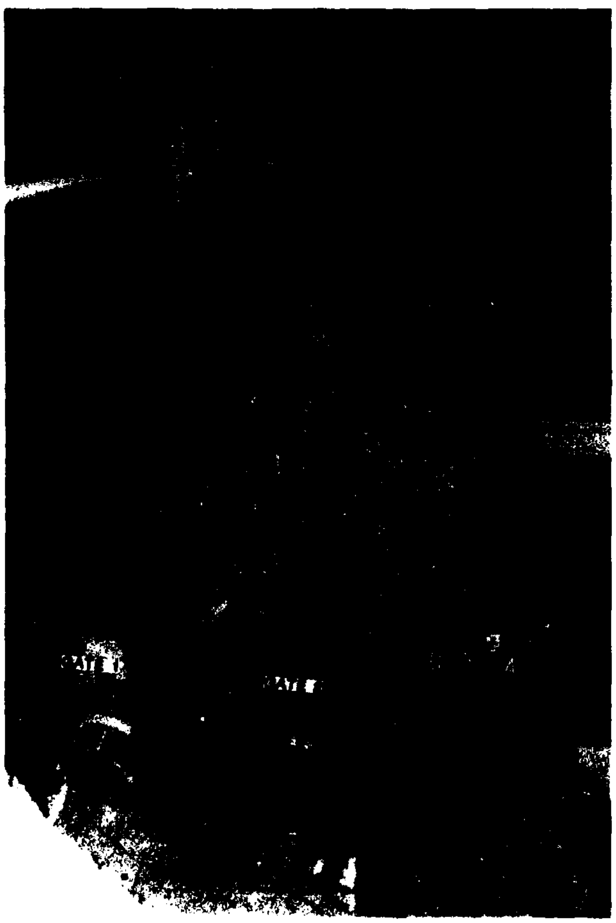


Figure 4. Discharge conduits and jet flow gates

14. Measurement of each of the dimensions or variables can be transformed quantitatively from model to prototype equivalents by these scale relations.

PART III: TESTS AND RESULTS

Jet Flow Gates

15. The outlet works including piezometer locations and the jet flow gates are shown in Plate 4. Model tests were conducted to calibrate the two identical jet flow gates for various gate openings, discharges, and heads. A sketch of one of the jet flow gates used in the model is shown in Plate 5. The test results permitted development of an equation by plotting discharge through jet flow gate 1 versus the energy head H_{01} on the center line of the discharge conduit at P_1 (Plate 4) and then plotting the constants for the equation in Plate 6 versus percent jet flow gate opening (Plate 7). The energy head (H_{01} and/or H_{02}) at P_1 and/or P_2 was obtained by subtracting the head loss H_ℓ from the vertical distance between the upper pool elevation and the elevation of the center line of the discharge conduits at P_1 and P_2 (el 5,575). The head loss values furnished by the US Army Engineer District, Sacramento, are shown in the following tabulation.

Discharge Q cfs	Head Loss H_ℓ ft
150	26.7
200	47.5
250	74.3
300	106.9
370	162.7

For identical gate openings and discharges, the heads at P_1 and P_2 were identical. Therefore, the following equations can be used for determining, for gate 1, gate 2, or both gates, the relative values of discharge, head, and percent gate opening:

$$Q_t = Q_1 + Q_2 \tag{1}$$

$$Q_t = 0.80(2g)^{1/2}\left[\left(\frac{A_{01}}{A_{T1}}\right)^{0.15} A_{01}H_{01}^{1/2} + \left(\frac{A_{02}}{A_{T2}}\right)^{0.15} A_{02}H_{02}^{1/2}\right] \tag{2}$$

where

Q_t = total discharge (gate 1 + gate 2), cfs

Q_1 = discharge for gate 1, cfs

Q_2 = discharge for gate 2, cfs

g = acceleration due to gravity, ft/sec^2

A_{01} = area of gate 1 opening, sq ft

A_{T1} = area of gate 1 full open, sq ft

H_{01} = energy head upstream of gate 1, ft

A_{02} = area of gate 2 opening, sq ft

A_{T2} = area of gate 2 full open, sq ft

H_{02} = energy head upstream of gate 2, ft

Discharge Conduits and Bifurcations

16. Tests were conducted to investigate the potential for cavitation in the two 36-in.-diam conduits and bifurcations. Average hydrostatic pressures in the discharge conduits and bifurcations were measured by piezometers. Piezometers were located in critical areas (Plate 4) to identify zones of potential cavitation. Pressures measured for various upper pool elevations are tabulated in Table 1. The upper pool elevation was simulated in the model by simulating the energy head (pressure head H_p + velocity head H_v) at P_1 and/or P_2 (Plate 4). The pressures in Table 1 are all positive and indicate that the discharge conduits and bifurcations will not be subject to cavitation.

Plunge Pool and Exit Channel

17. Tests were conducted to evaluate riprap stability in the plunge pool and exit channel. Details of the original design plunge pool and exit channel are shown in Plate 8. The plunge pool and exit channel were lined with riprap and subjected to various flow releases from the jet flow gates with upper pool elevations of 5,685, 5,750, 5,798 and 5,810. The upper pool elevations were simulated in the model by setting the pressure head H_p at P_1 and/or P_2 (Plate 4). H_p was determined by the following equation:

$$H_p = \text{Pool El} - \text{℄ Outlet El} - H_\ell - H_v \qquad (3)$$

where

℄ Outlet El = 5,575

H_ℓ = calculated head loss from intake to cross section where H_p was measured

H_v = velocity head at cross section where H_p was measured

For each test, the riprap was subjected to a constant hydraulic condition for a period of 3 hr (prototype), and then the plunge pool and exit channel were drained and inspected for riprap displacement.

Original design (type 1 plunge pool and exit channel)

18. Initially the plunge pool and exit channel were lined with 18-in. riprap (Figure 3). The prototype riprap gradation limits and the riprap gradation simulated in the model for the 18-in. riprap (Figure 3) are shown in Plate 9. The gradation curves in Plate 9 indicate that the model riprap gradation was designed to be conservative. The riprap used in the model had a unit weight of 160 pcf. If the proposed prototype rock has a different unit weight than the rock used in the model, then the thickness of the prototype riprap T_2 should be adjusted by the following equation:

$$T_2 = \frac{T_1}{\dfrac{\left(\dfrac{\gamma_{s2} - \gamma_w}{\gamma_w}\right)}{\left(\dfrac{\gamma_{s1} - \gamma_w}{\gamma_w}\right)}} \qquad (4)$$

where

T_2 = thickness required in prototype, in.

T_1 = thickness simulated in model, in.

γ_{s2} = unit weight of riprap to be used in prototype, pcf

γ_w = unit weight of water in prototype, pcf

γ_{s1} = unit weight of riprap used in model, pcf

19. Various flow conditions with a single gate and both gates operating are shown in Photo 1. Hydraulic parameters, including the percentage gate opening G_o, and whether or not failure occurred are shown. Typical riprap failure zones are illustrated in Photo 2. Sketches indicating failure zones

and distance from gate to impact zone are shown in Plate 10. Wave heights (amplitudes) measured in the locations shown in Plate 11 are tabulated in Table 2. Various flow conditions with riprap stability characteristics indicated are tabulated in Table 3.

20. In areas where failure occurred, the 18-in. riprap was replaced with 24-in. riprap (type 2 riprap design) as shown in Plate 12. The riprap gradation simulated in the model for the 24-in. riprap is shown in Plate 13. Tests indicated that the 24-in. riprap also failed under similar hydraulic conditions in the areas where the 18-in. riprap had failed.

Recommended design (type 2 plunge pool and exit channel) and type 3 riprap design

21. The plunge pool and exit channel were revised to provide flatter side slopes as shown in Plate 14 (type 2 plunge pool and exit channel). The plunge pool and exit channel were lined with 18-in. riprap as shown in Figure 5. Various flow conditions are illustrated in Photo 3. Riprap stability characteristics for various flow conditions are tabulated in Table 4. The 18-in. riprap was stable for all flow conditions except for a

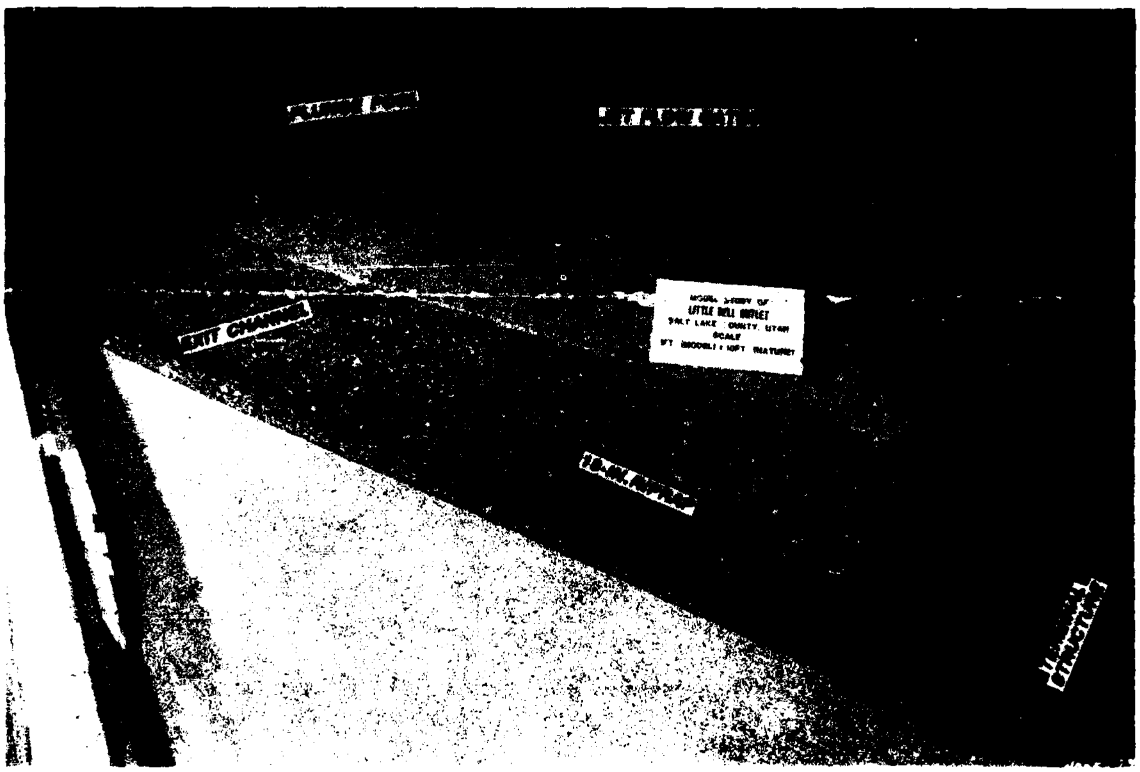


Figure 5. Type 2 plunge pool and exit channel

flow of 150 cfs through jet flow gate 1 with a pool el 5,798.0. The area where the riprap was displaced is shown in Photo 4 and Plate 15. The 18-in. riprap was replaced with 24-in. riprap in the area shown in Plate 16 (type 3 riprap design). Riprap stability characteristics for various flow conditions are tabulated in Table 5. Wave heights (amplitudes) measured in the locations shown in Plate 11 are tabulated in Table 2. Although the wave heights were consistently higher with the type 2 plunge pool, the magnitude of the wave height was not severe with either of the designs. The type 2 plunge pool and exit channel and type 3 riprap design were subjected to various anticipated flow conditions and satisfactory energy dissipation with no riprap displacement observed.

PART IV: SUMMARY AND DISCUSSION

22. Model tests conducted to calibrate the jet flow gates permitted the development of an equation relating the following parameters: (a) discharge, (b) head on center line of gate, and (c) gate opening. The equation can be used for determining, for gate 1, gate 2, or both gates, the relative values of discharge, head, and percent gate opening.

23. Tests were conducted to investigate the potential for cavitation in the bifurcations and the two 36-in.-diam conduits for various heads and flow rates. The pressures measured by piezometers were positive and indicate that the outlet works should not be subject to cavitation.

24. Riprap failure was observed in the original design plunge pool and exit channel for numerous anticipated flow conditions with single or multiple gate operation. The geometry of the plunge pool and exit channel was modified (type 2 plunge pool and exit channel) to provide flatter side slopes more conducive to riprap stability. The revised design was stable for all anticipated flow conditions except for one area of 18-in. riprap that failed with 150 cfs passing through a single gate. The area of 18-in. riprap that failed was replaced with 24-in. riprap (type 3 riprap design). The type 2 plunge pool and exit channel lined with the type 3 riprap design (Plate 16) was subjected to various anticipated flow conditions, and no riprap failure was observed.

Table 1

Pressures in Little Dell Outlet Works

Piezometer* No.	Piezometer* El	Pressures in Prototype Feet of Water: Discharge Gate 1 203 cfs Gate 2 203 cfs Pool El 5,810 Gate Opening 100%	Discharge Gate 1 185 cfs Gate 2 185 cfs Pool El 5,810	Discharge Gate 1 150 cfs Gate 2 150 cfs Pool El 5,740	Discharge Gate 1 100 cfs Gate 2 100 cfs Pool El 5,665
1	5,575.00	23±2	63±2	52	41
2		12±2	49±2	42±2	38
3		19±2	56±2	46±2	42
4		13±2	48±2	42	38
5		18±2	54±2	44	39
6		22±2	57±2	49±2	42
7		26±7	62±8	52±5	43±3
8		22±3	57±3	47±2	42±2
9	5,576.25	38±4	79±4	61±3	47±3

* Piezometer locations are shown in Plate 4.

Table 2

Wave Heights

Pool El	Discharge, cfs	Gate Opening percent Gate 1	Gate 2	Wave Height, ft, for Location* 1	2	3	4	5
Type 1 Plunge Pool and Exit Channel Design								
Type 1 Riprap Design								
(Original Design)								
5,685	150	57	--	0.2	0.3	0.5	0.4	0.4
5,685	150	--	57	0.3	0.5	0.5	0.5	0.5
5,798	300	49	49	0.4	1.0	1.2	1.0	0.5
5,798	150	39	--	0.5	0.7	1.0	1.0	0.7
5,798	150	--	39	0.2	0.5	1.2	0.7	0.4
5,810	370	77	77	0.4	1.2	1.5	1.5	1.1
Type 2 Plunge Pool and Exit Channel Design**								
Type 3 Riprap Design								
(Recommended Design)								
5,685	150	57	--	0.7	0.8	0.9	0.8	0.6
5,685	150	--	57	0.8	0.9	0.9	0.9	0.8
5,798	300	49	49	0.6	1.2	1.3	1.3	0.8
5,798	150	39	--	0.7	1.0	1.3	1.4	1.0
5,798	150	--	39	0.4	0.7	1.3	1.0	0.7
5,810	370	77	77	0.5	1.4	1.7	1.7	1.4

* See Plate 11.

** See Plate 16.

Table 3

Riprap Stability Characteristics

Type 1 Plunge Pool and Exit Channel Design

18-in. Riprap

Pool El	Discharge, cfs		Gate Opening, percent		Riprap Failure	
	Gate 1	Gate 2	Gate 1	Gate 2	No	Yes
5,685	50	--	20	--	x	
	150	--	57	--		x
	--	50	--	20	x	
	--	150	--	57		x
	50	50	20	20	x	
	75	75	31	31	x	
5,740	50	--	16	--		x
	150	--	46	--		x
	--	150	--	16	x	
	--	150	--	46		x
	50	50	17	17	x	
	75	75	25	25	x	
	150	150	66	66	x	
5,798	50	--	14	--	x	
	150	--	39	--		x
	--	50	--	14	x	
	--	150	--	39		x
	50	50	15	15	x	
	75	75	21	21		x
	150	150	49	49		x
5,810	185	185	77	77		x
	203	203	100	100	x	

Note: Test duration 3 hr (prototype).

Table 4

Riprap Stability Characteristics

Type 2 Plunge Pool and Exit Channel Design

18-in. Riprap

Pool El	Discharge, cfs Gate 1	Discharge, cfs Gate 2	Gate Opening, percent Gate 1	Gate Opening, percent Gate 2	Riprap Failure No	Riprap Failure Yes
5,685	50	--	20	--	x	
	150	--	57	--	x	
	--	50	--	20	x	
	--	150	--	57	x	
	50	50	20	20	x	
	75	75	31	31	x	
5,740	50	--	16	--	x	
	150	--	46	--	x	
	--	50	--	16	x	
	--	150	--	46	x	
	50	50	17	17	x	
	75	75	25	25	x	
	150	150	66	66	x	
5,798	50	--	14	--	x	
	150	--	39	--		x
	--	50	--	14	x	
	--	150	--	39	x	
	50	50	15	15	x	
	75	75	21	21	x	
	150	150	49	49	x	
5,810	185	185	77	77	x	
	203	203	100	100	x	

Note: Test duration 3 hr (prototype).

Table 5

Riprap Stability Characteristics

Type 2 Plunge Pool and Exit Channel Design

Type 3 Riprap Design

18- and 24-in. Riprap

Pool El	Discharge, cfs Gate 1	Discharge, cfs Gate 2	Gate Opening, percent Gate 1	Gate Opening, percent Gate 2	Riprap Failure No	Riprap Failure Yes
5,685	50	--	20	--	x	
	150	--	57	--	x	
	--	50	--	20	x	
	--	150	--	57	x	
	50	50	20	20	x	
	75	75	31	31	x	
5,740	50	--	16	--	x	
	150	--	46	--	x	
	--	50	--	16	x	
	--	150	--	46	x	
	50	50	17	17	x	
	75	75	25	25	x	
	150	150	66	66	x	
5,798	50	--	14	--	x	
	150	--	39	--	x	
	--	50	--	14	x	
	--	150	--	39	x	
	50	50	15	15	x	
	75	75	21	21	x	
	150	150	49	49	x	
5,810	185	185	77	77	x	
	203	203	100	100	x	

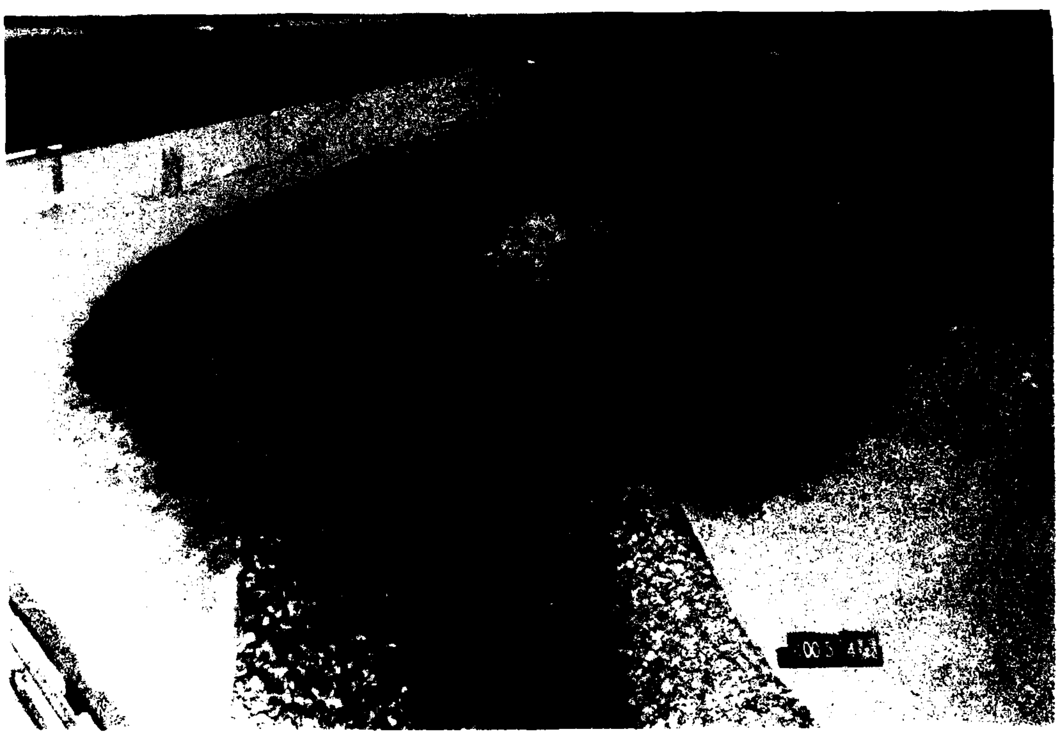
Note: Test duration 3 hr (prototype).

a. Pool el 5,685, gate 1 discharge 50 cfs and opening 20 percent, gate 2 closed, no rock failure after 3 hr operation (prototype)

b. Pool el 5,685, gate 1 closed, gate 2 discharge 150 cfs and opening 57 percent, rock failure after 3 hr operation (prototype)

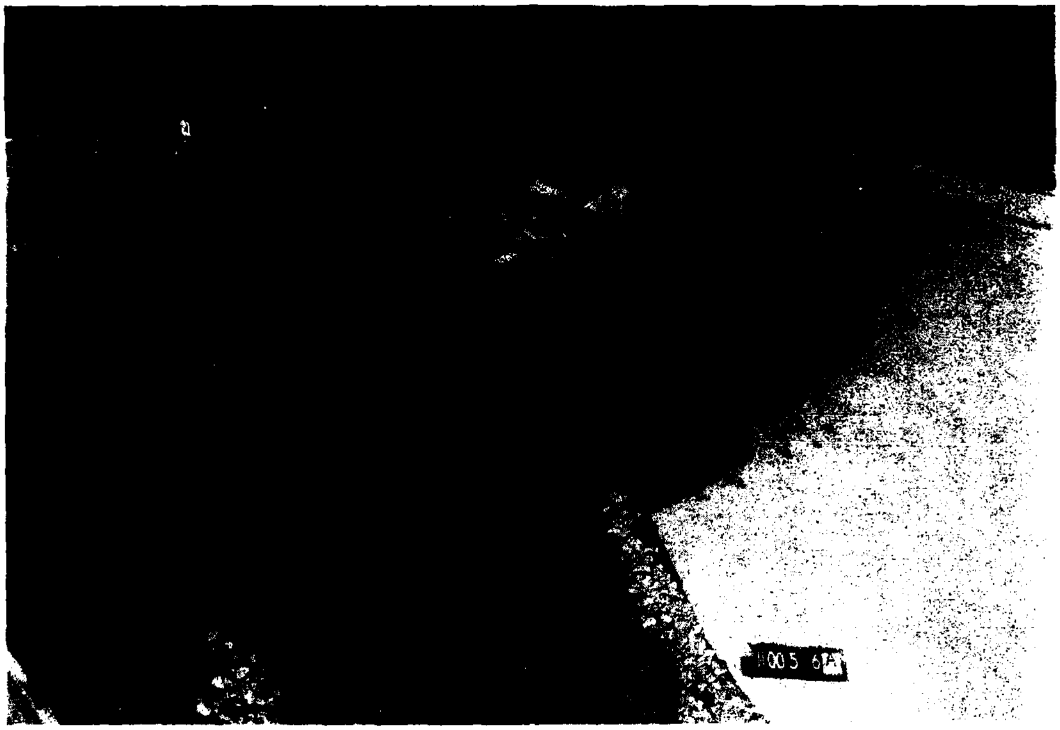
Photo 1. Various flow conditions, type 1 plunge pool and exit channel (Sheet 1 of 6)

c. Pool el 5,685, gate 1 discharge 50 cfs and opening 20 percent, gate 2 discharge 50 cfs and opening 20 percent, no rock failure after 3 hr operation (prototype)



d. Pool el 5,740, gate 1 discharge 50 cfs and opening 17 percent, gate 2 discharge 50 cfs and opening 17 percent, no rock failure after 3 hr operation (prototype)

Photo 1. (Sheet 2 of 6)



e. Pool el 5,740, gate 1 discharge 150 cfs and opening 66 percent, gate 2 discharge 150 cfs and opening 66 percent, no rock failure after 3 hr operation (prototype)

f. Pool el 5,798, gate 1 closed, gate 2 discharge 50 cfs and opening 14 percent, no rock failure after 3 hr operation (prototype)

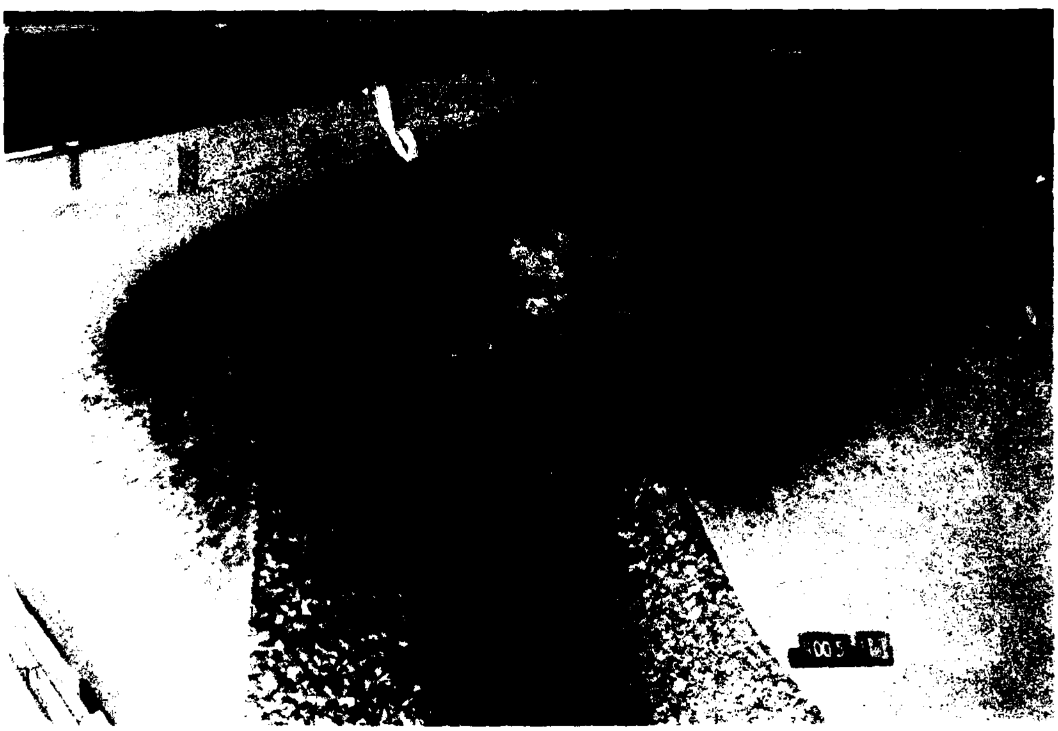
Photo 1. (Sheet 3 of 6)

g. Pool el 5,798, gate 1 discharge 50 cfs and opening 14 percent, gate 2 closed, no rock failure after 3 hr operation (prototype)

h. Pool el 5,798, gate 1 closed, gate 2 discharge 150 cfs and opening 39 percent, rock failure after 3 hr operation (prototype)

Photo 1. (Sheet 4 of 6)

i. Pool el 5,798, gate 1 discharge 150 cfs and opening 39 percent, gate 2 closed, rock failure after 3 hr operation (prototype)



j. Pool el 5,798, gate 1 discharge 50 cfs and gate opening 15 percent, gate 2 discharge 50 cfs and gate opening 15 percent, no rock failure after 3 hr operation (prototype)

Photo 1. (Sheet 5 of 6)

k. Pool el 5,798, gate 1 discharge 150 cfs and opening 49 percent, gate 2 discharge 150 cfs and opening 49 percent, rock failure after 3 hr operation (prototype)

l. Pool el 5,810, gate 1 discharge 185 cfs and gate opening 77 percent, gate 2 discharge 185 cfs and gate opening 77 percent, rock failure after 3 hr operation (prototype)

Photo 1. (Sheet 6 of 6)

a. Pool el 5,798, gate 1 discharge 150 cfs and opening 39 percent, gate 2 closed, after 3 hr operation (prototype)

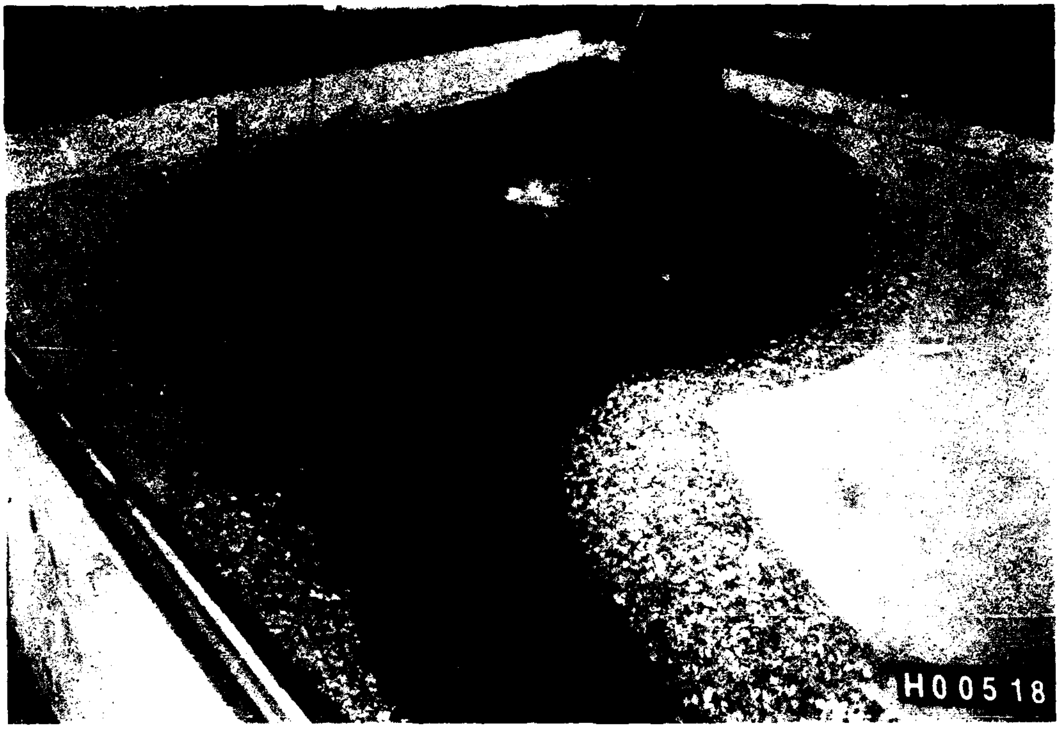
b. Pool el 5,798, gate 1 discharge 150 cfs and opening 49 percent, gate 2 discharge 150 cfs and opening 49 percent, after 3 hr operation (prototype)

Photo 2. Typical failure zones, type 1 plunge pool and exit channel

a. Pool el 5,685, gate 1 discharge 50 cfs and opening 20 percent, gate 2 closed

b. Pool el 5,685, gate 1 discharge 150 cfs and opening 57 percent, gate 2 closed

Photo 3. Various flow conditions, type 2 plunge pool and exit channel (Sheet 1 of 9)



c. Pool el 5,740, gate 1 discharge 50 cfs and opening 16 percent, gate 2 closed

d. Pool el 5,740, gate 1 discharge 150 cfs and gate opening 46 percent, gate 2 closed

Photo 3. (Sheet 2 of 9)

e. Pool el 5,798, gate 1 discharge 50 cfs and opening 14 percent, gate 2 closed

f. Pool el 5,798, gate 1 discharge 150 cfs and opening 39 percent, gate 2 closed

Photo 3. (Sheet 3 of 9)

g. Pool el 5,685, gate 1 closed, gate 2 discharge 50 cfs and opening 20 percent

h. Pool el 5,685, gate 1 closed, gate 2 discharge 150 cfs and gate opening 57 percent

Photo 3. (Sheet 4 of 9)

i. Pool el 5,740, gate 1 closed, gate 2 discharge 50 cfs and opening 16 percent

j. Pool el 5,740, gate 1 closed, gate 2 discharge 150 cfs and gate opening 46 percent

Photo 3. (Sheet 5 of 9)

k. Pool el 5,798, gate 1 closed, gate 2 discharge 50 cfs and opening 14 percent

l. Pool el 5,798, gate 1 closed, gate 2 discharge 150 cfs and opening 39 percent

Photo 3. (Sheet 6 of 9)

m. Pool el 5,685, gate 1 discharge 50 cfs and opening 20 percent, gate 2 discharge 50 cfs and opening 20 percent

n. Pool el 5,740, gate 1 discharge 50 cfs and opening 17 percent, gate 2 discharge 50 cfs and opening 17 percent

Photo 3. (Sheet 7 of 9)

o. Pool el 5,740, gate 1 discharge 150 cfs and opening 66 percent, gate 2 discharge 150 cfs and gate opening 66 percent

p. Pool el 5,798, gate 1 discharge 50 cfs and opening 15 percent, gate 2 discharge 50 cfs and opening 15 percent

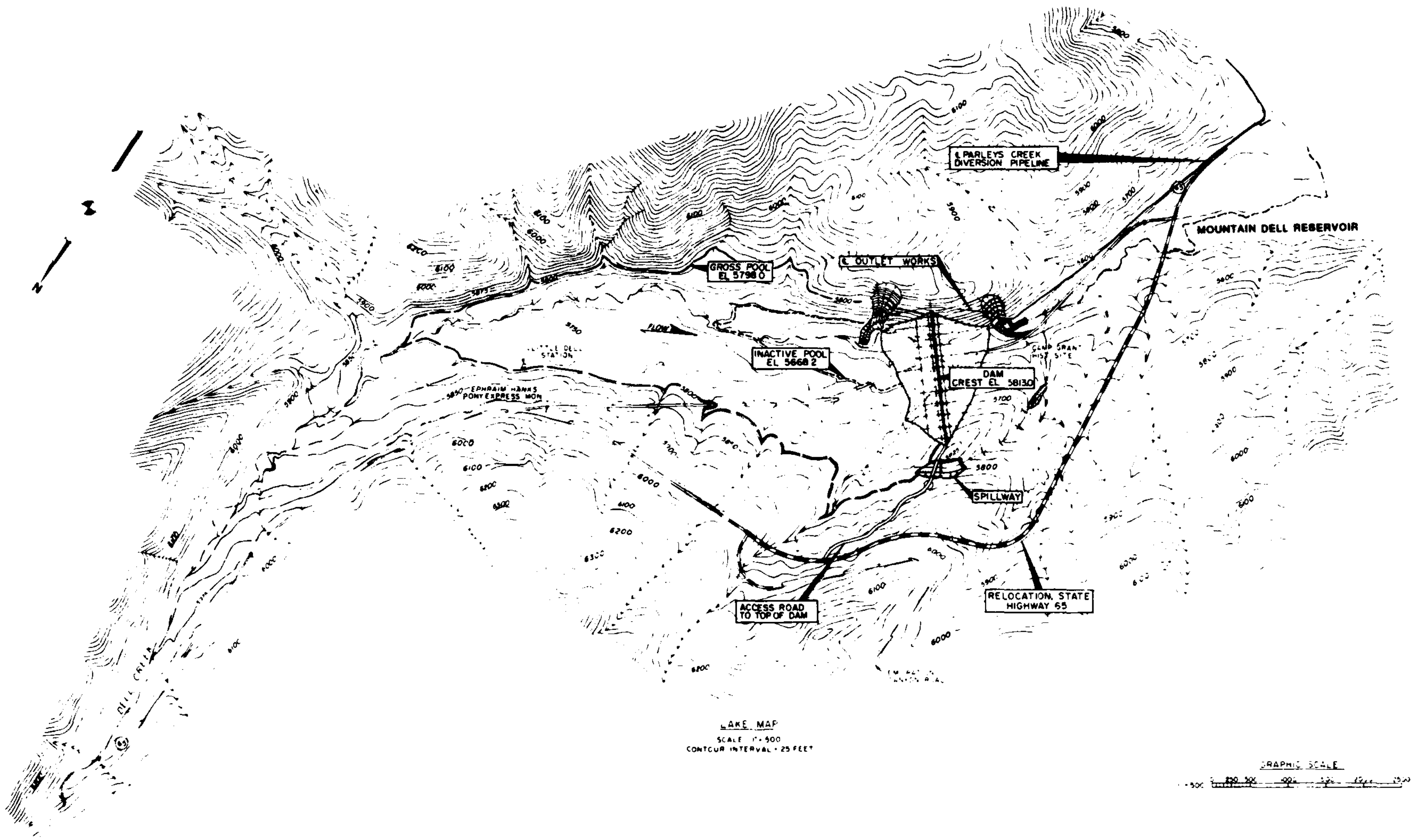
Photo 3. (Sheet 8 of 9)

q. Pool el 5,798, gate 1 discharge 150 cfs and opening 49 percent, gate 2 discharge 150 cfs and opening 49 percent

r. Pool el 5,810, gate 1 discharge 203 cfs and opening 100 percent, gate 2 discharge 203 cfs and gate opening 100 percent

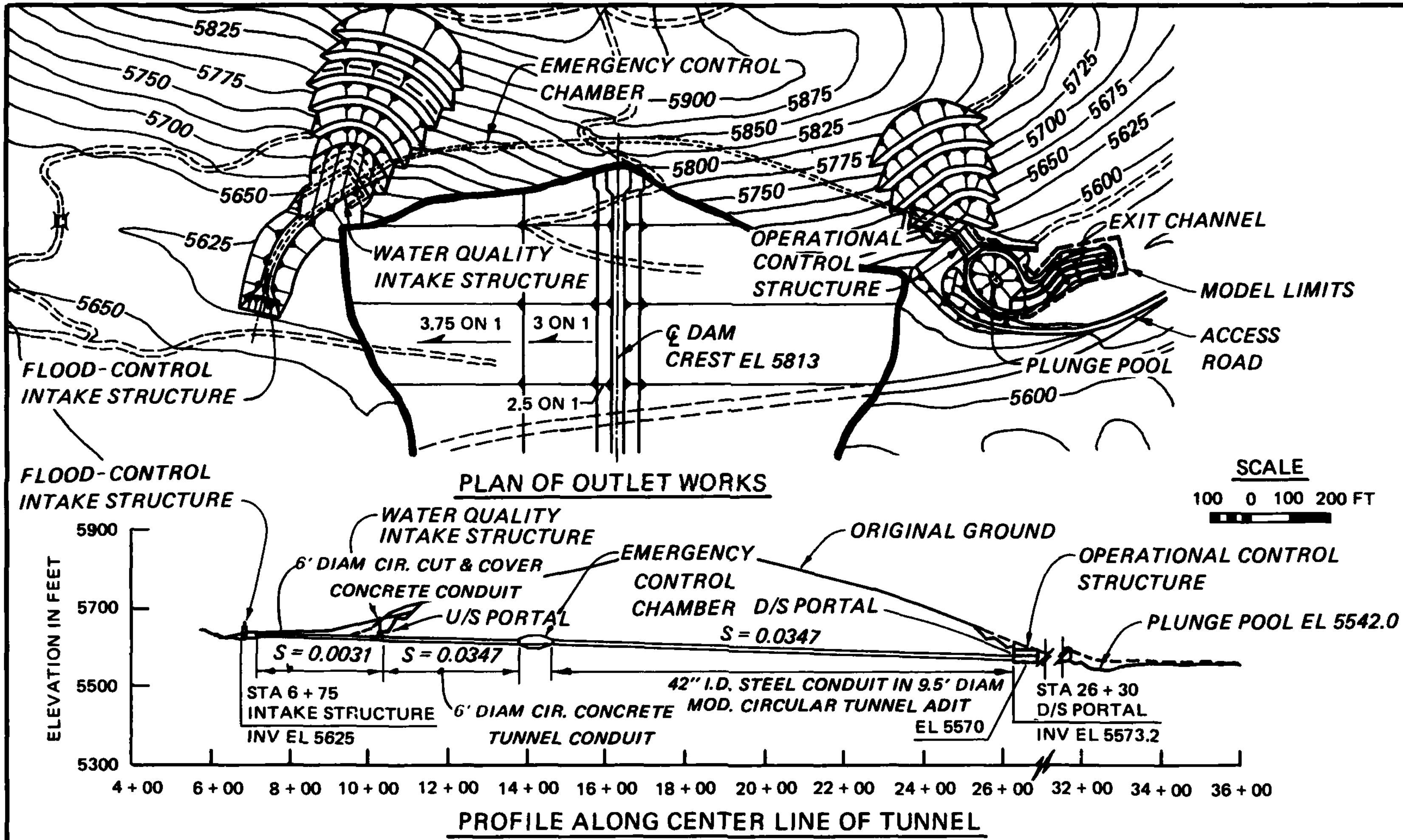
Photo 3. (Sheet 9 of 9)

Photo 4. Riprap failure, view from downstream, type 2 plunge pool and exit channel, 18-in. riprap, gate 1 discharge 150 cfs and opening 39 percent, gate 2 closed, pool el 5,798, test duration 3 hr (prototype)

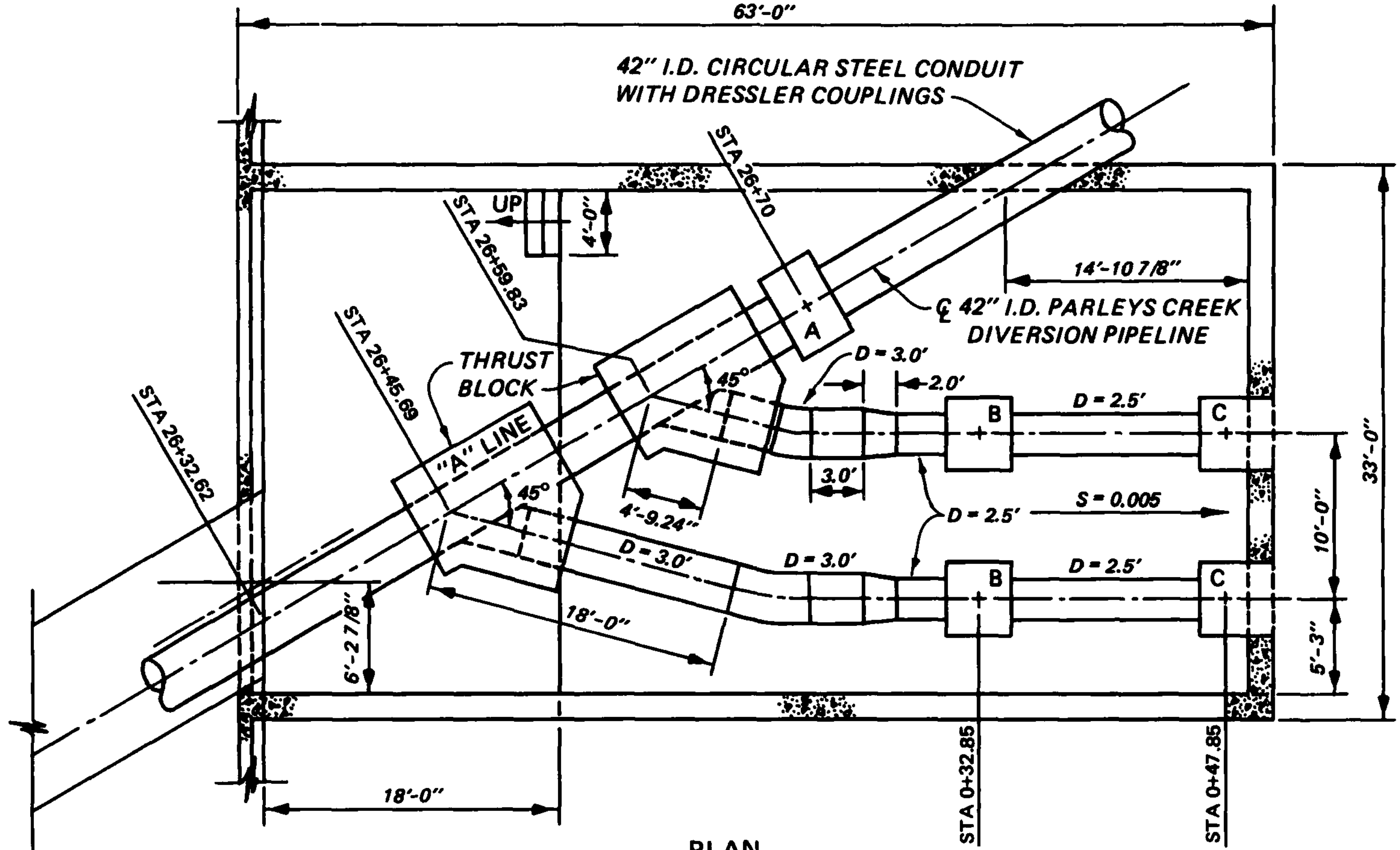


PROJECT PLAN

PLATE 2



PLAN AND PROFILE

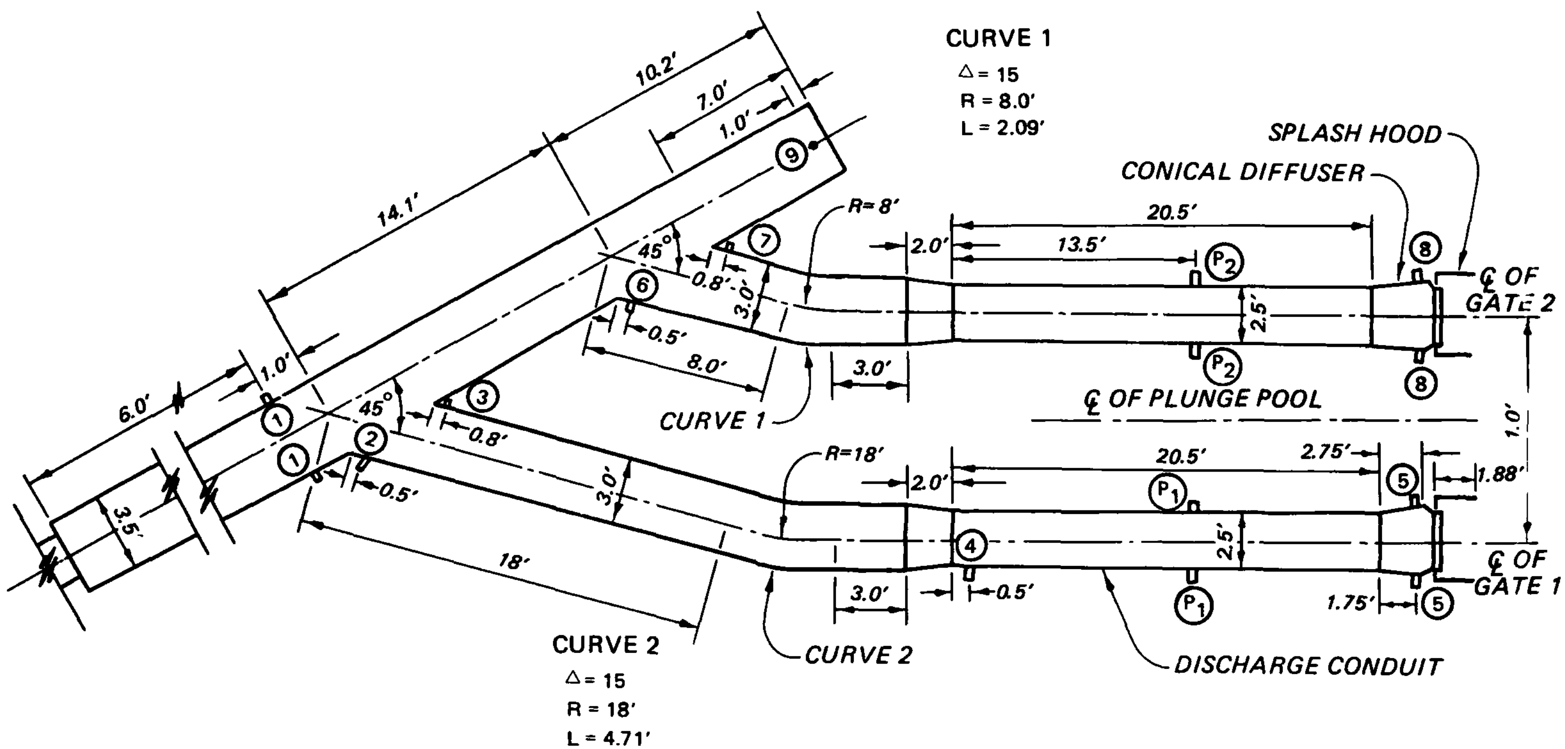


PLAN

LEGEND

A = 42" I.D. DIRECTIONAL BUTTERFLY VALVE
B = 30" I.D. BALL TYPE GUARD VALVES
C = 30" I.D. JET FLOW GATES

OPERATIONAL CONTROL STRUCTURE

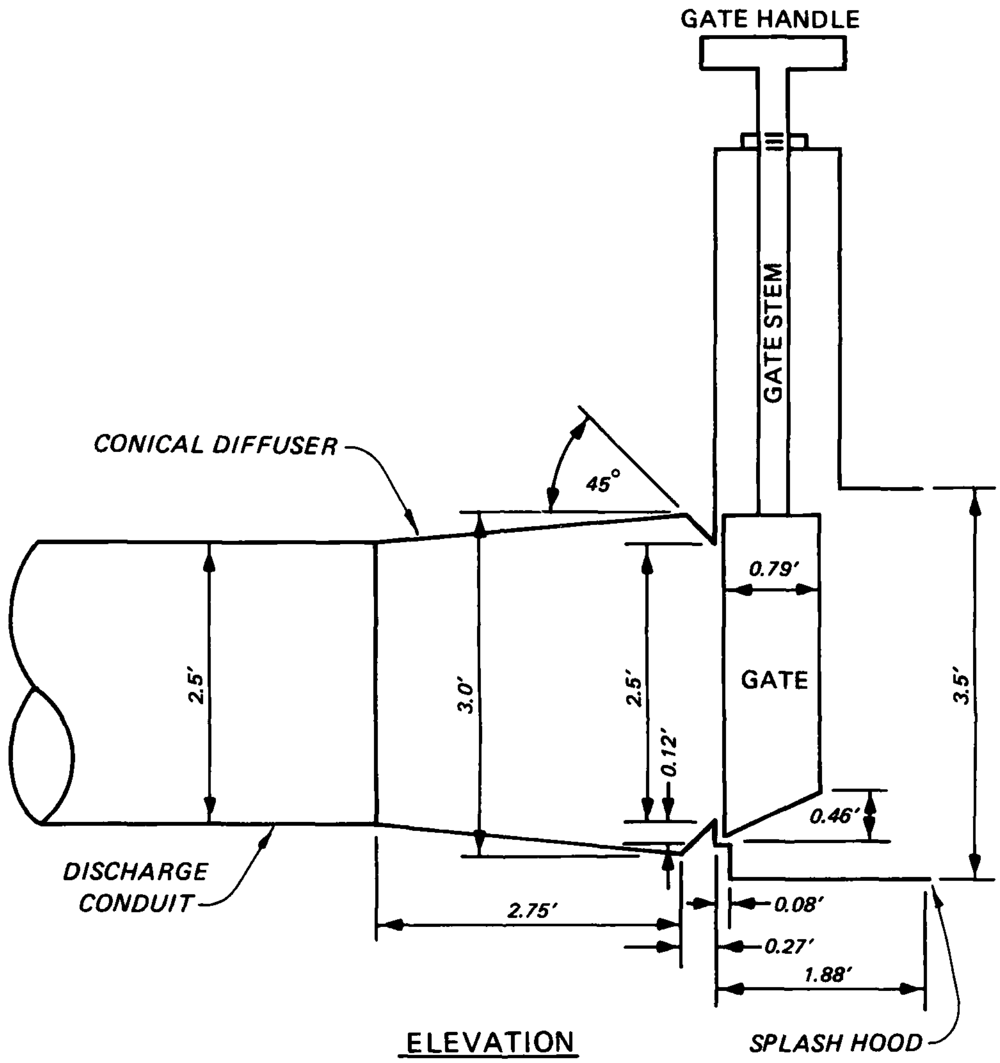


PLAN

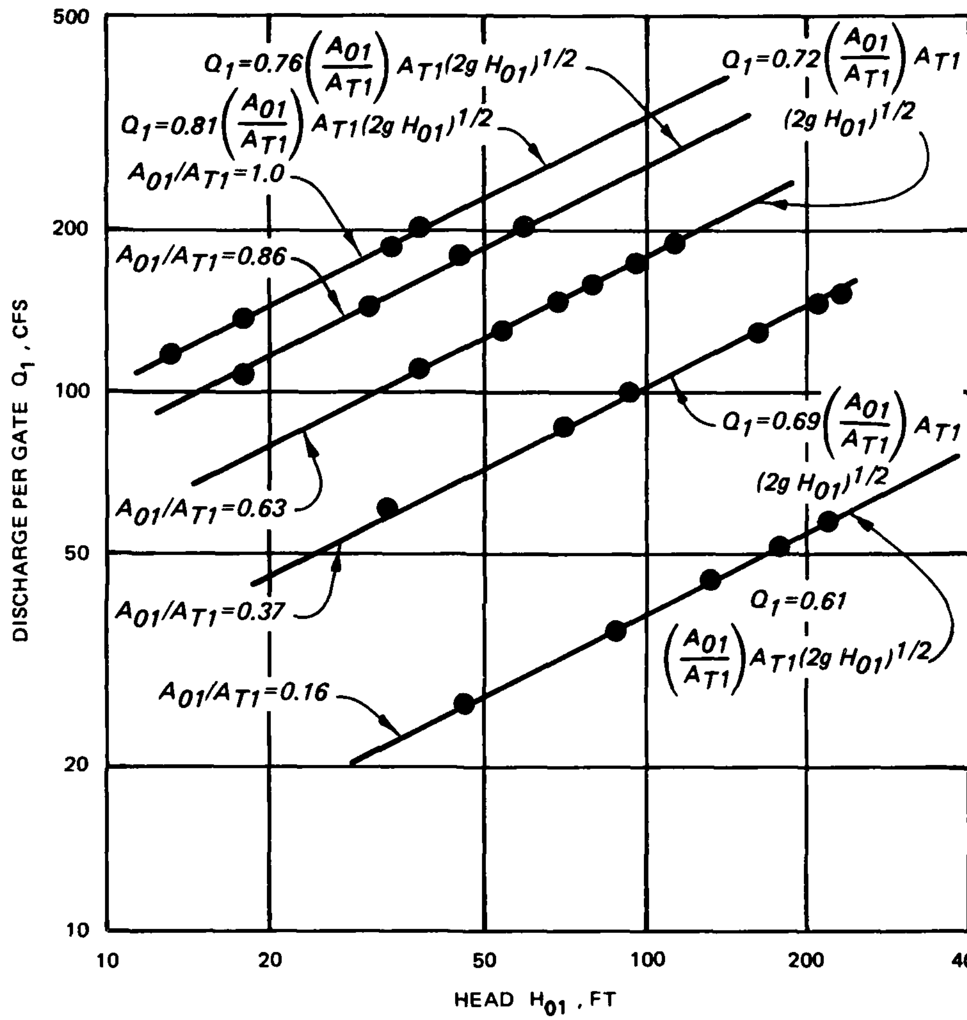
NOTE: ALL PIEZOMETERS ARE LOCATED ON THE SIDE OF CONDUIT ON THE ℄ EXCEPT PIEZOMETER NO. 9. PIEZOMETER NO. 9 IS LOCATED ON TOP OF THE CONDUIT.

(1) INDICATES PIEZOMETER NUMBER.

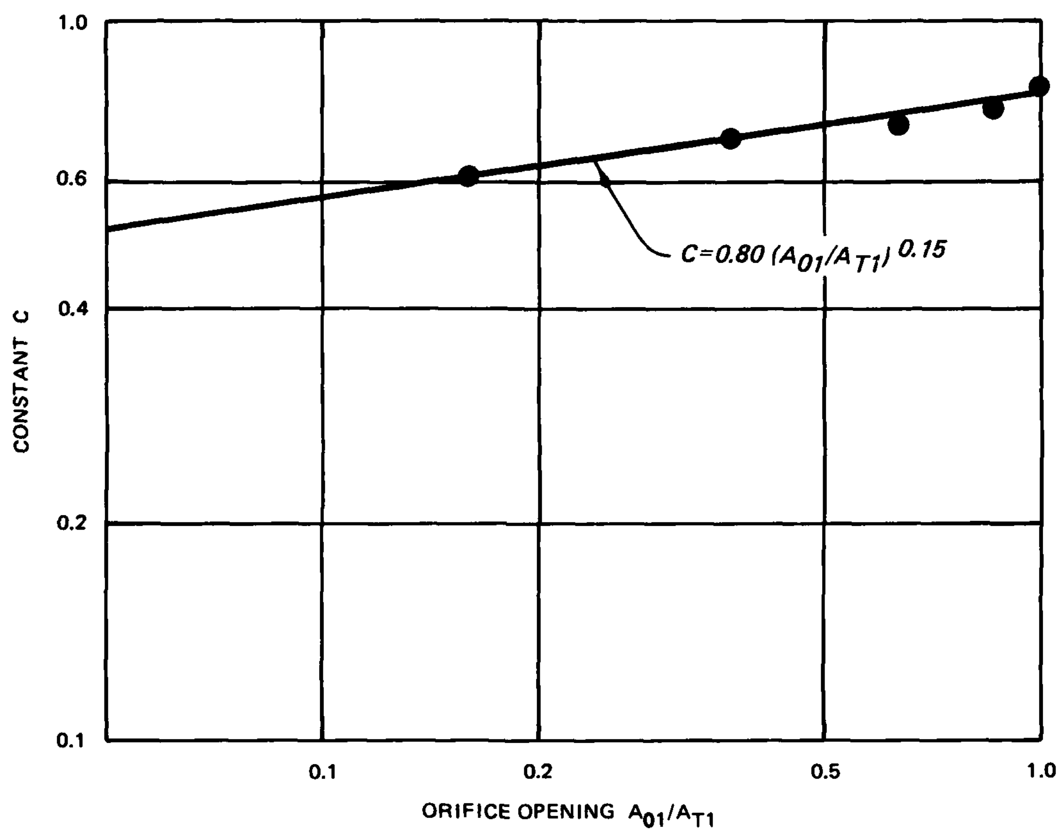
PIEZOMETER LOCATIONS



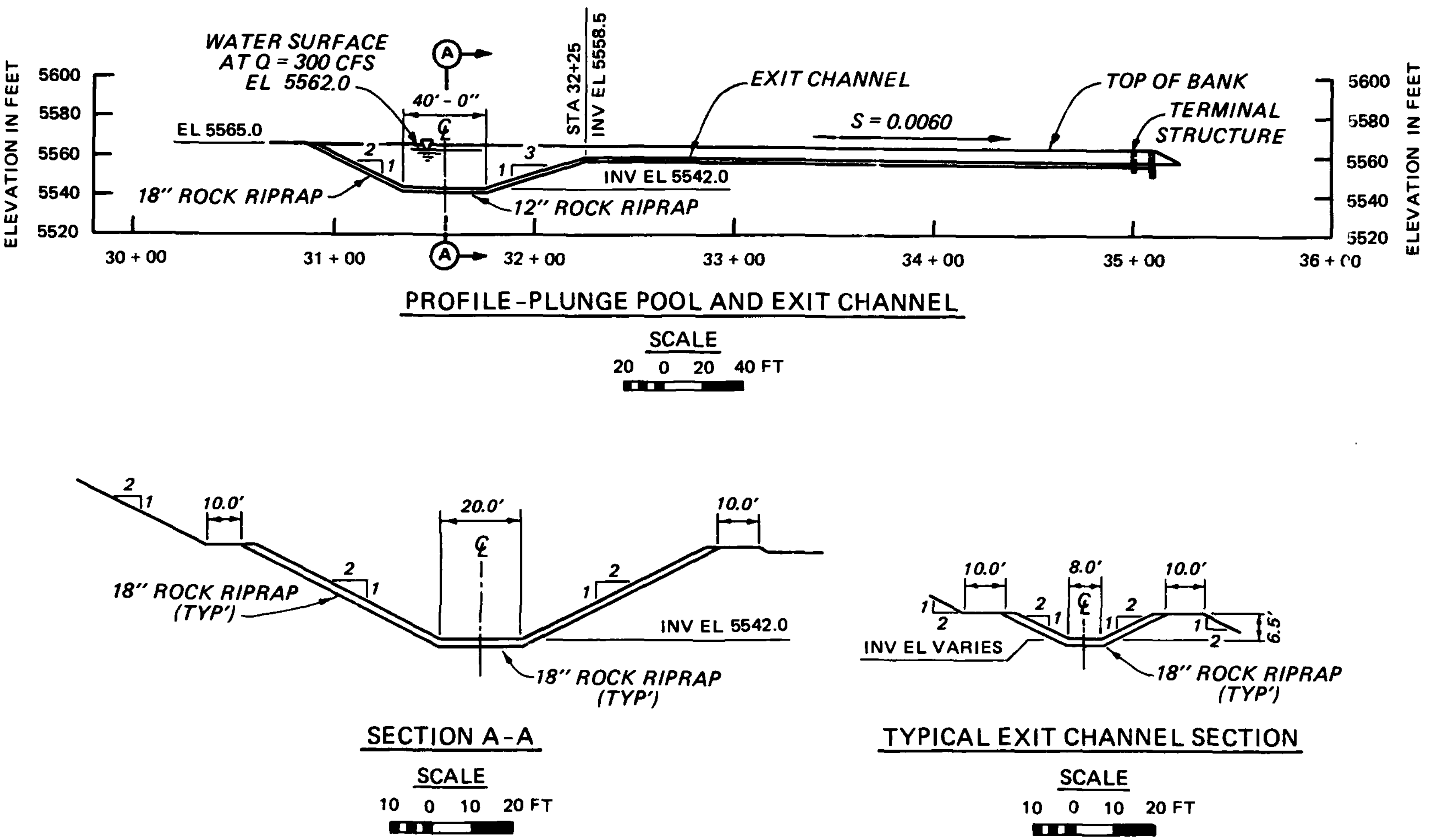
JET FLOW GATE



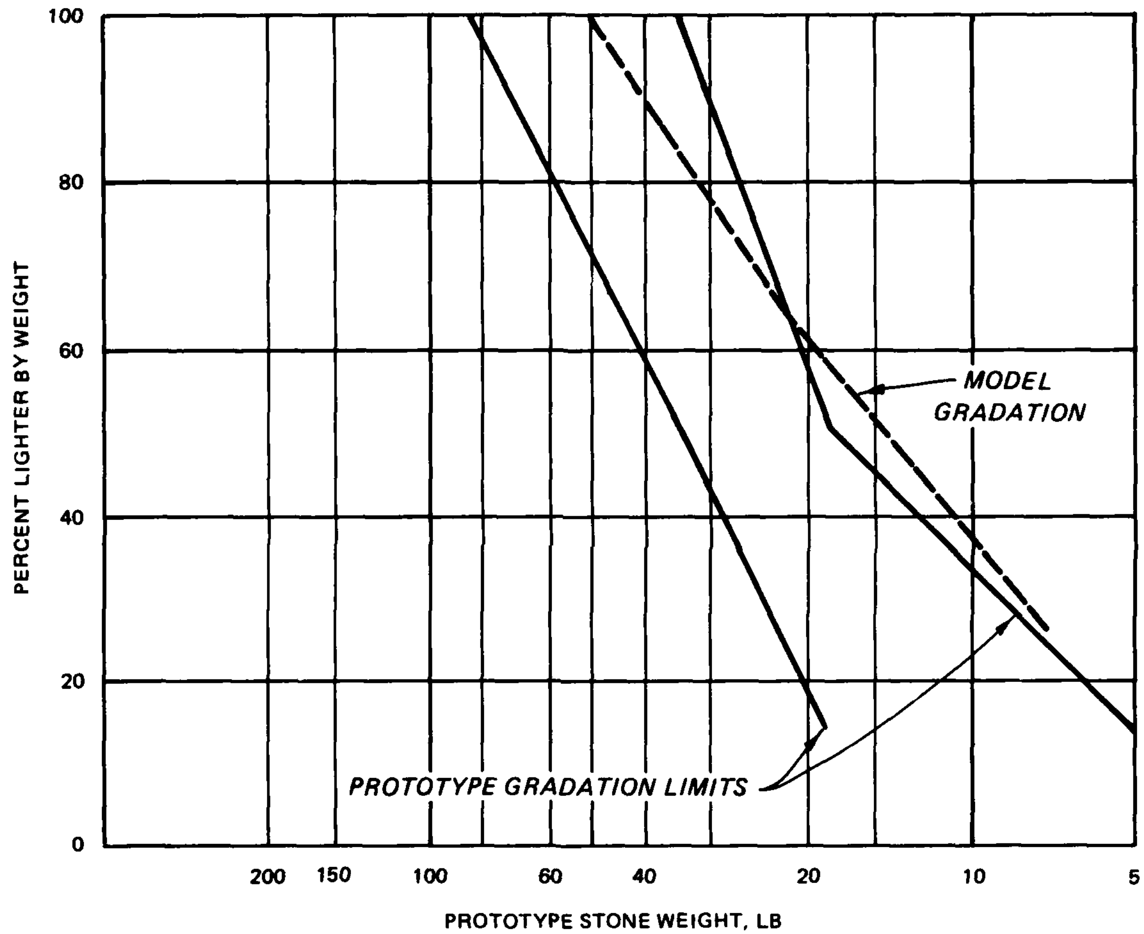
DISCHARGE PER GATE VERSUS HEAD ON CENTER LINE OF DISCHARGE CONDUIT



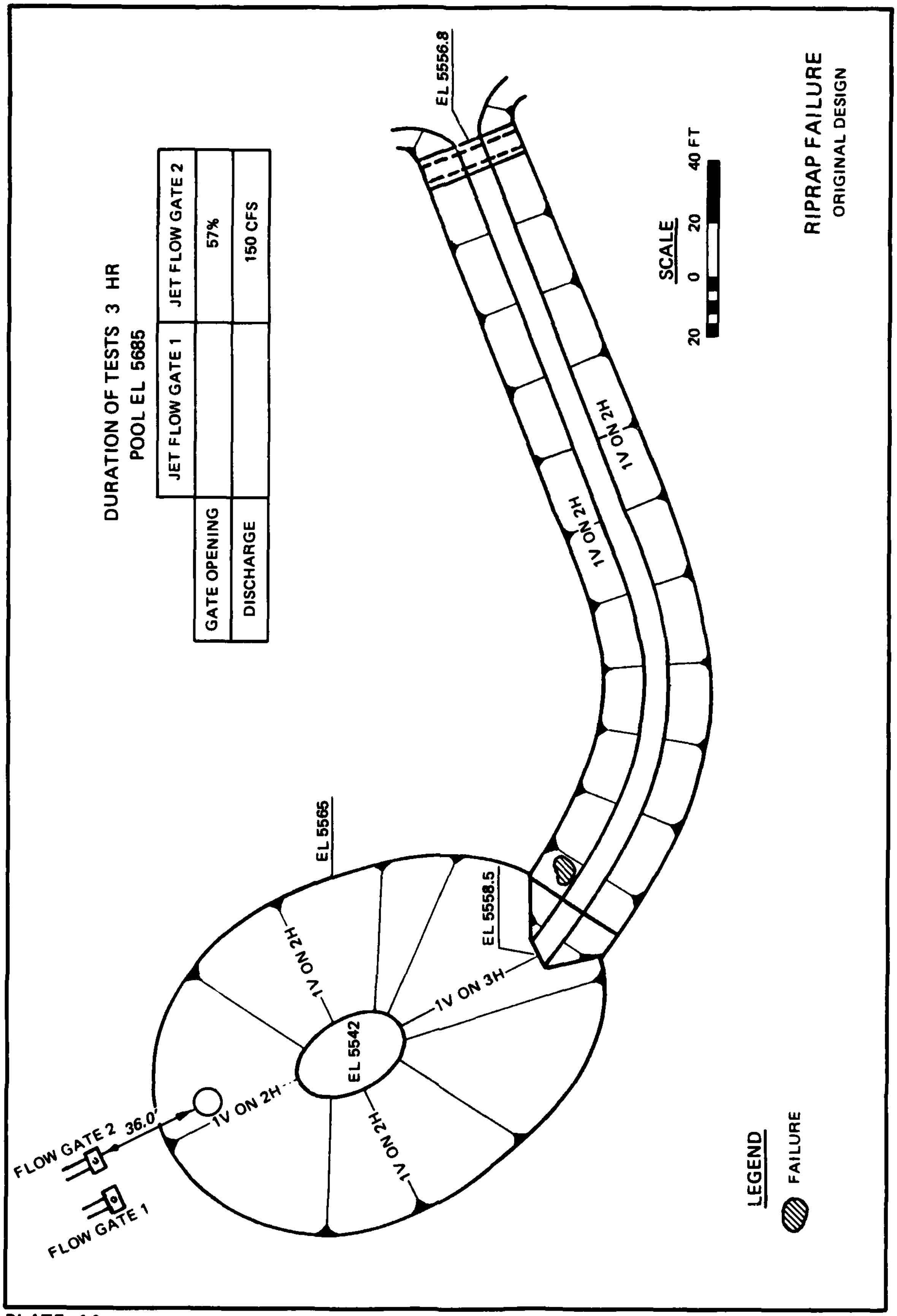
CONSTANT VERSUS RATIO OF ORIFICE AREA TO AREA OF FULL GATE OPENING



PLUNGE POOL AND EXIT CHANNEL
SECTIONS AND DETAILS
ORIGINAL DESIGN

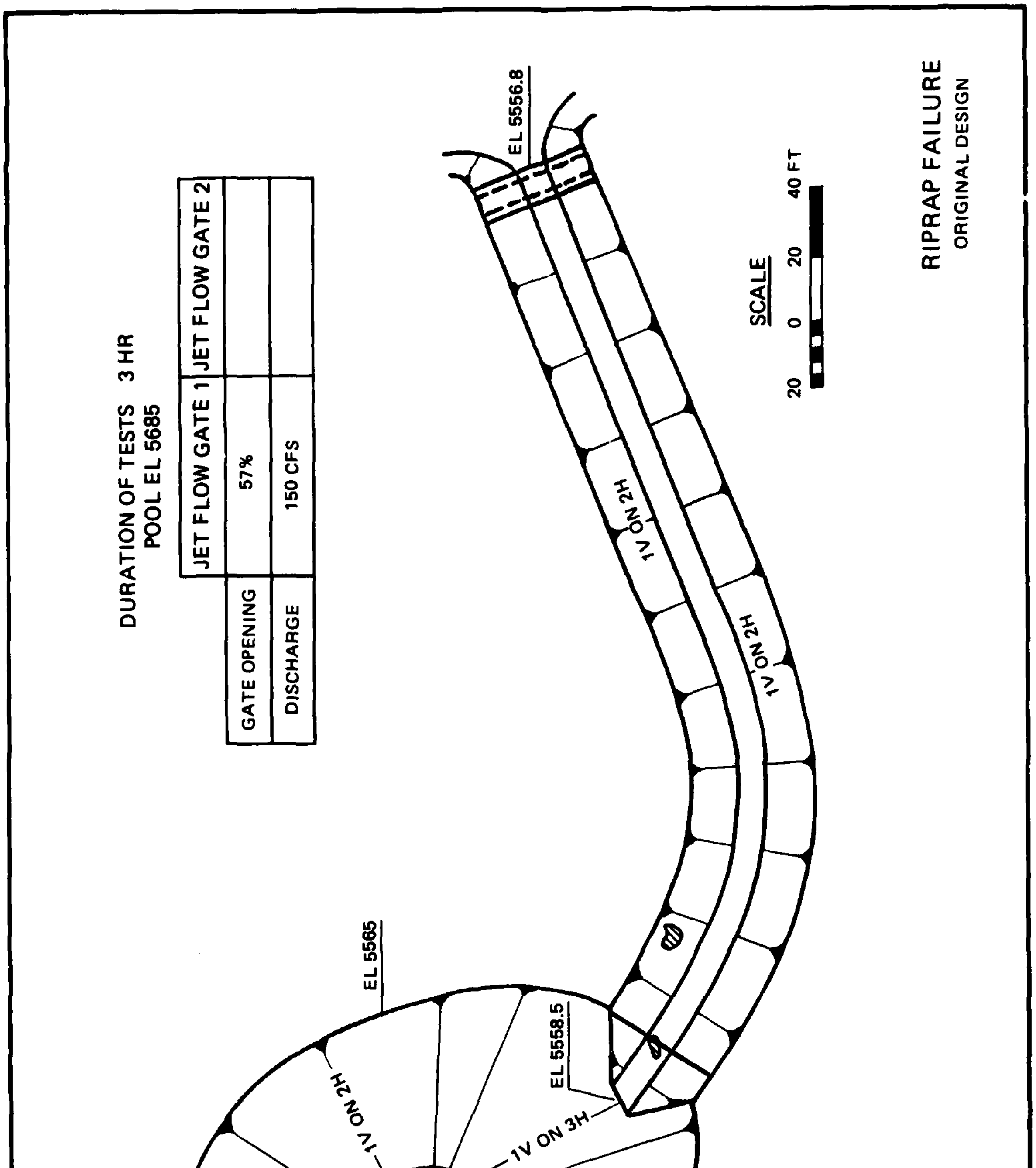


RIPRAP GRADATION
18 INCH



	JET FLOW GATE 1	JET FLOW GATE 2
GATE OPENING		57%
DISCHARGE		150 CFS

PLATE 10
(SHEET 1 OF 6)



	JET FLOW GATE 1	JET FLOW GATE 2
GATE OPENING	57%	
DISCHARGE	150 CFS	

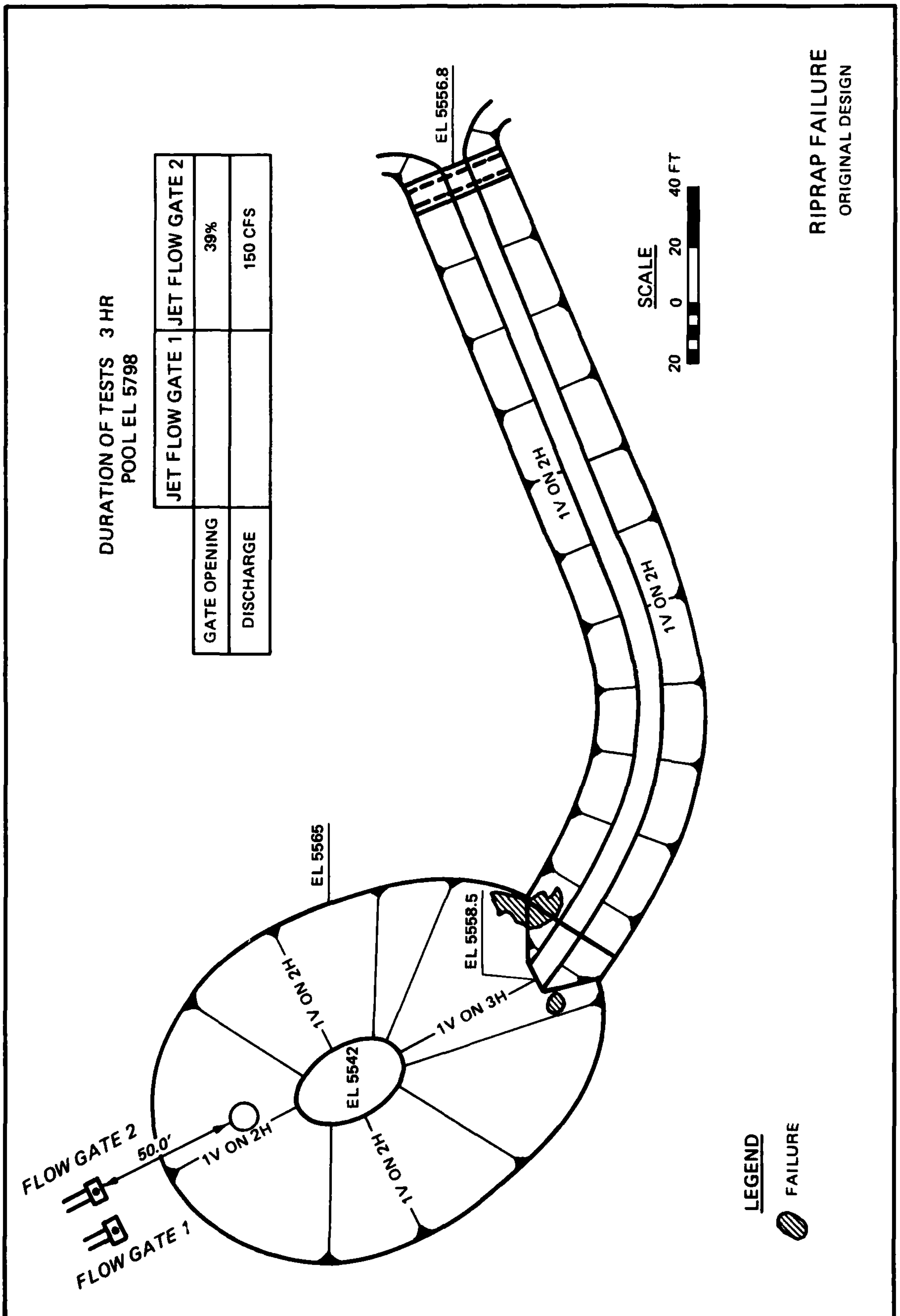
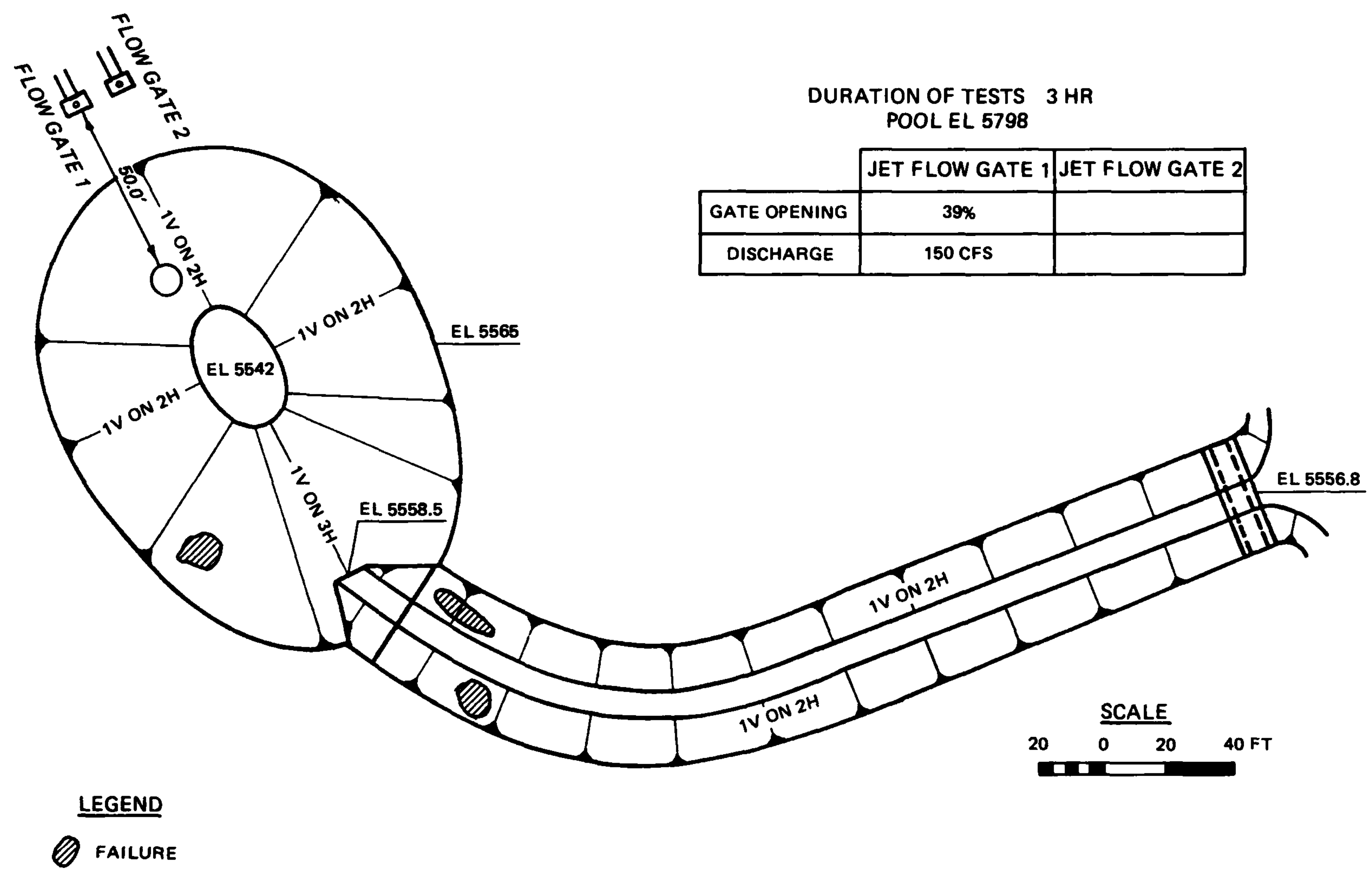


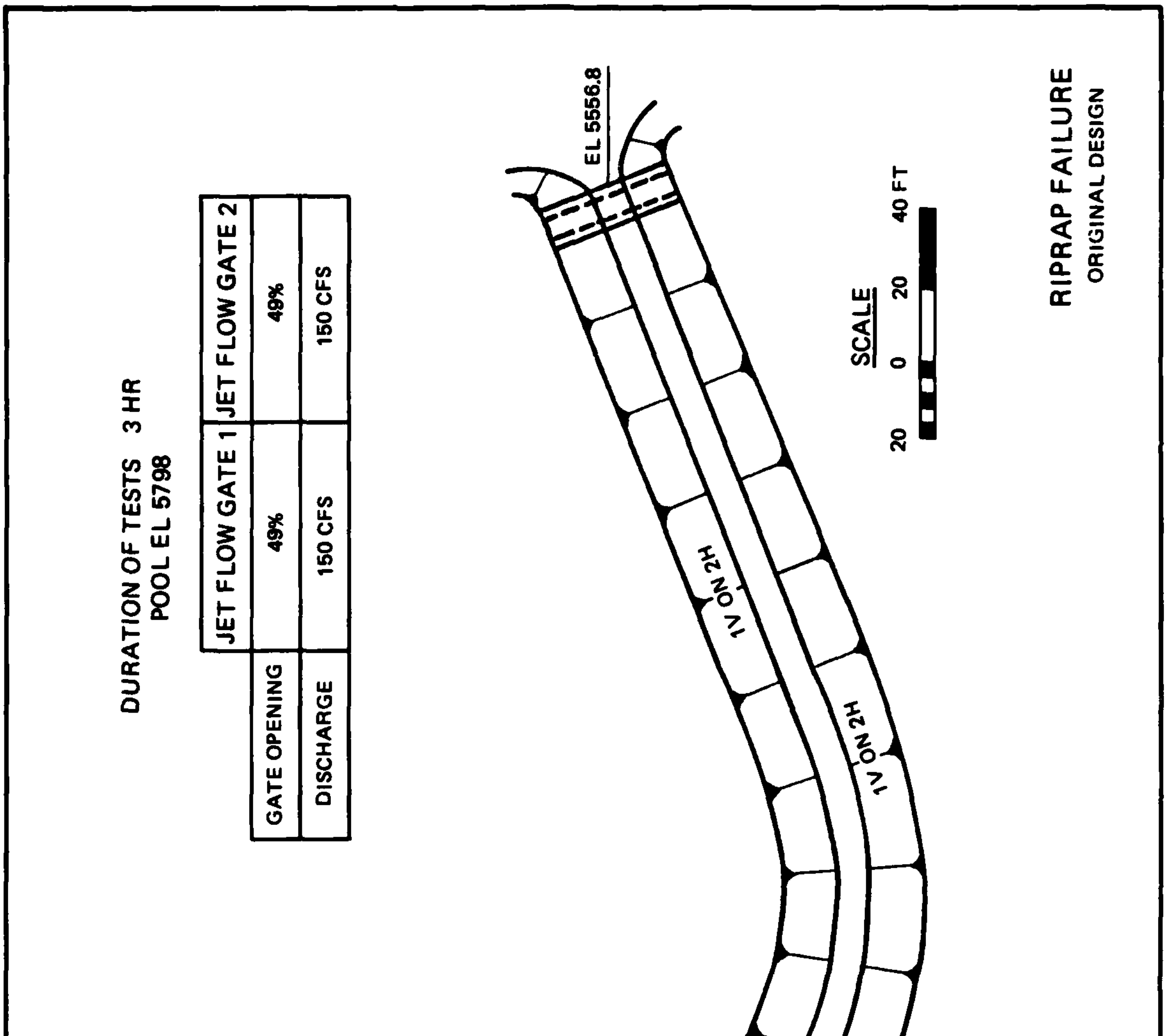
PLATE 10
(SHEET 3 of 6)

DURATION OF TESTS 3 HR
POOL EL 5798

	JET FLOW GATE 1	JET FLOW GATE 2
GATE OPENING	39%	
DISCHARGE	150 CFS	



RIPRAP FAILURE
ORIGINAL DESIGN

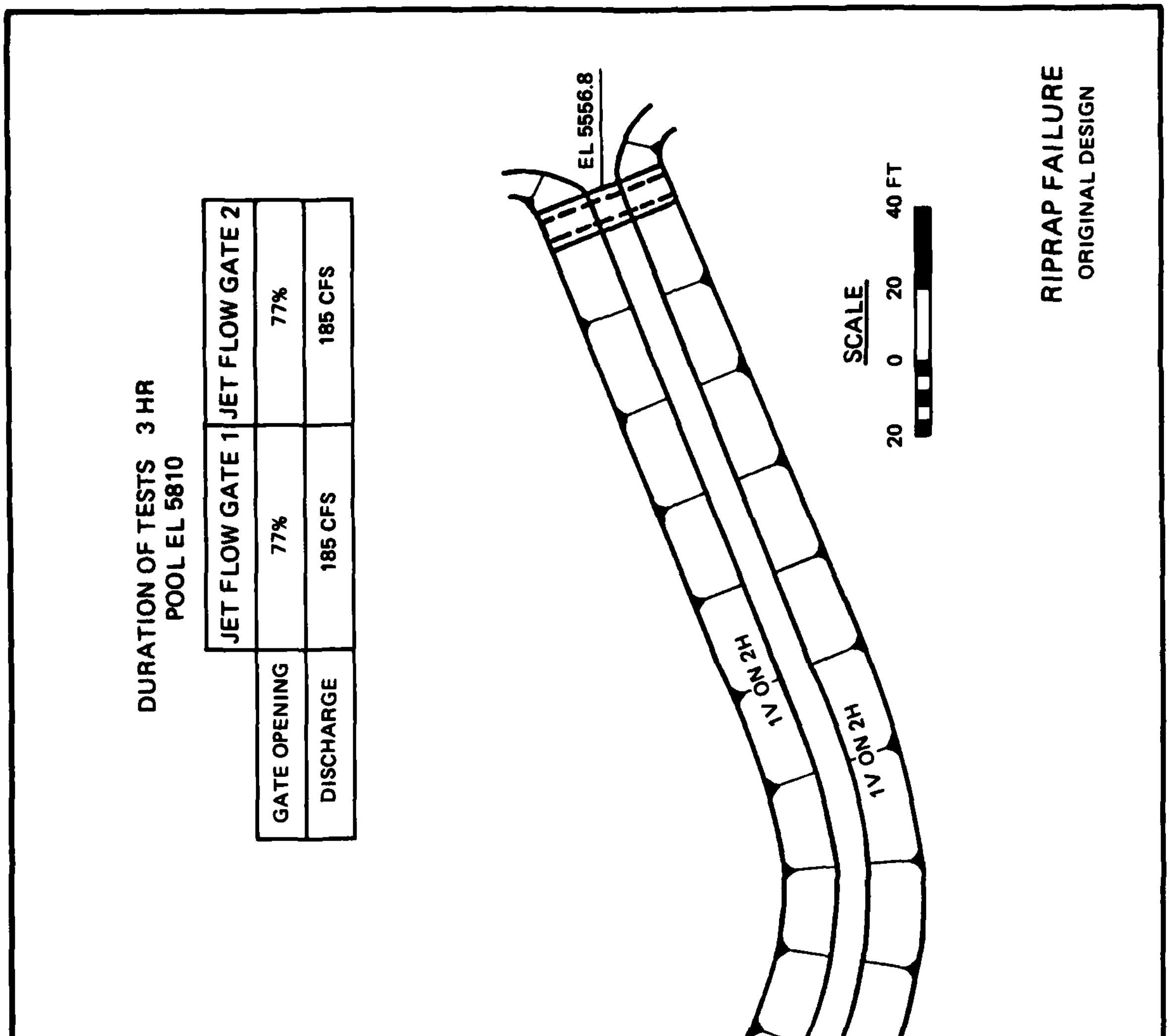


	JET FLOW GATE 1	JET FLOW GATE 2
GATE OPENING	49%	49%
DISCHARGE	150 CFS	150 CFS

PLATE 10
(SHEET 5 OF 6)

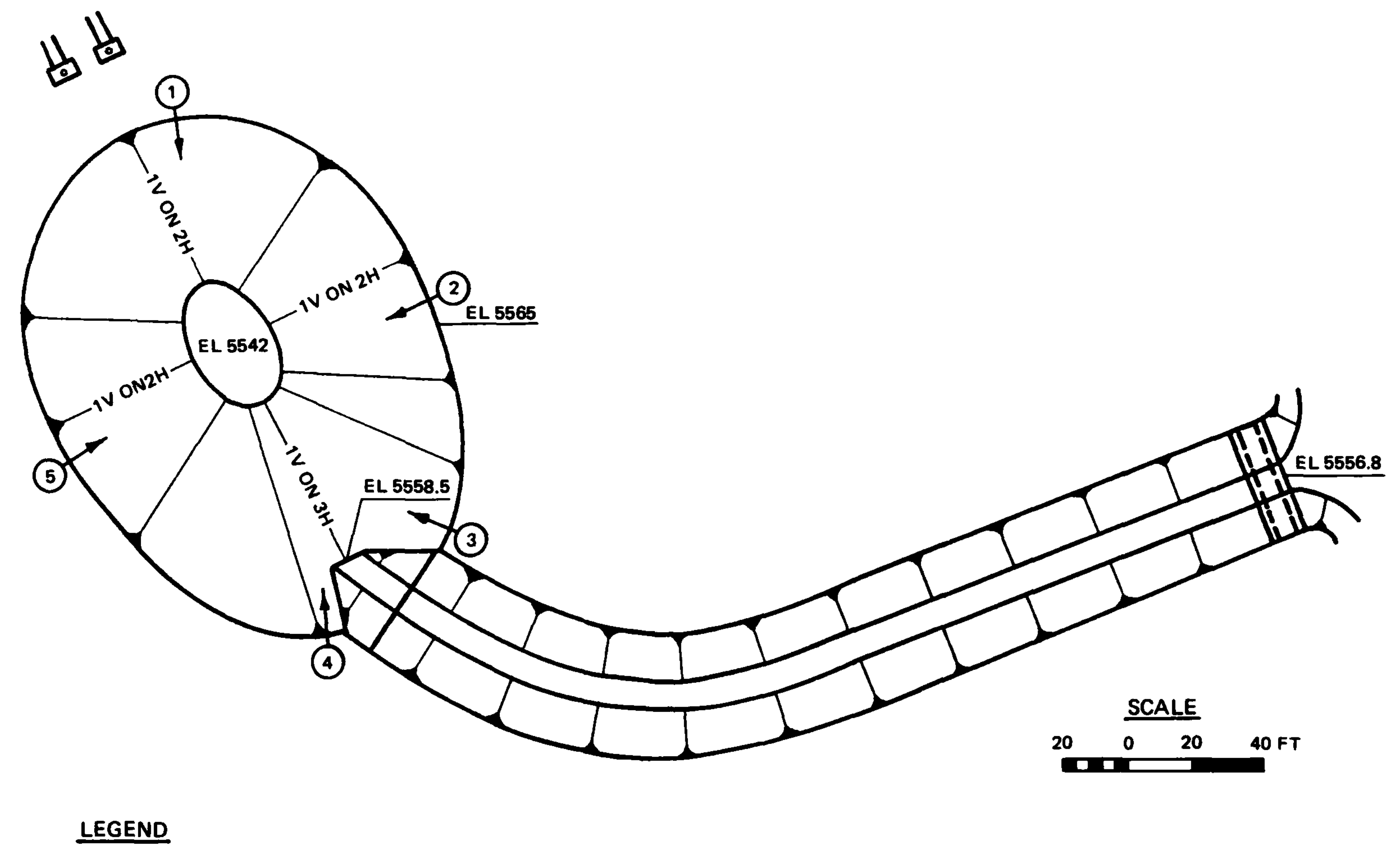
DURATION OF TESTS 3 HR
POOL EL 5810

	JET FLOW GATE 1	JET FLOW GATE 2
GATE OPENING	77%	77%
DISCHARGE	185 CFS	185 CFS

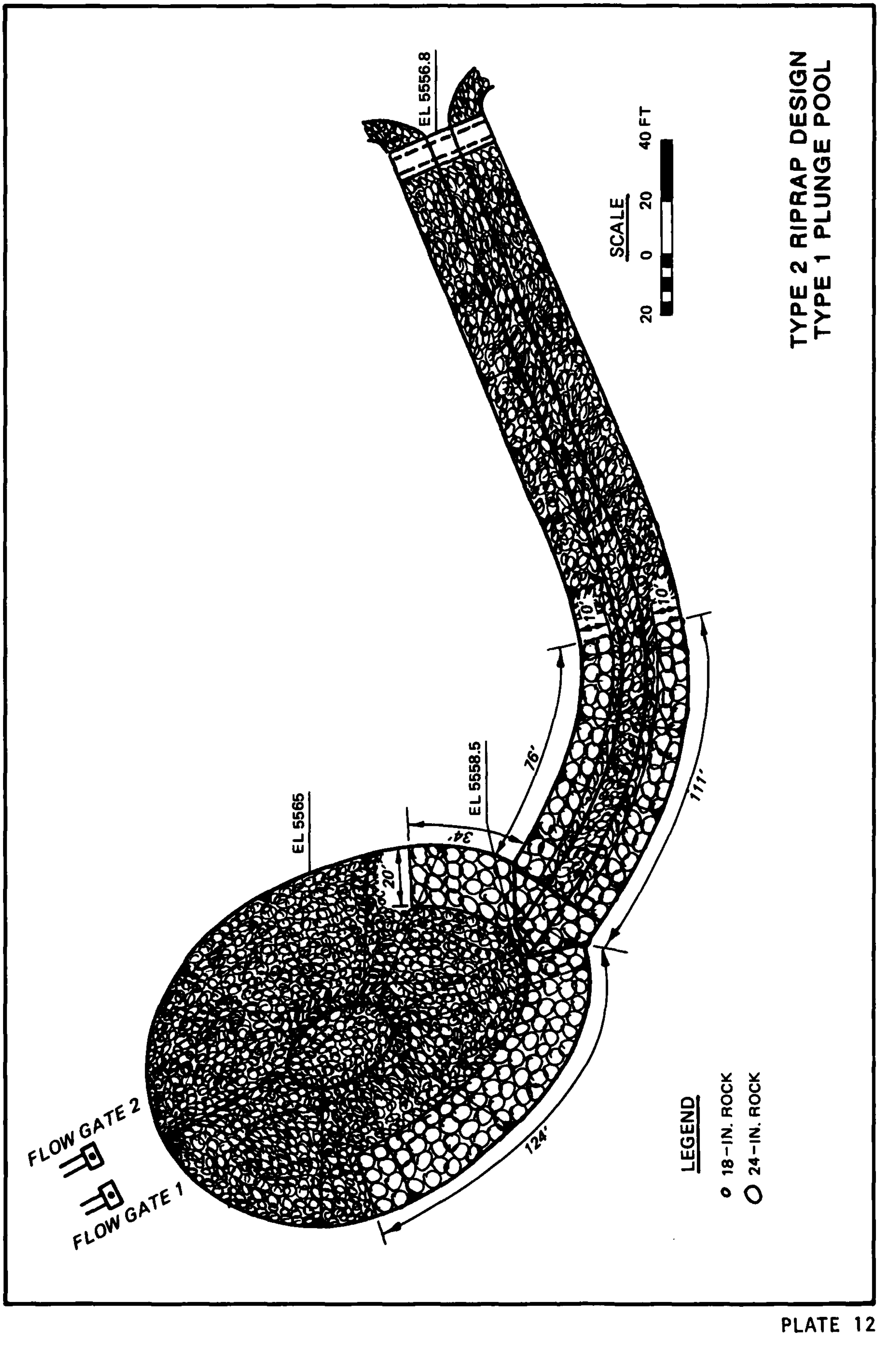


RIPRAP FAILURE
ORIGINAL DESIGN

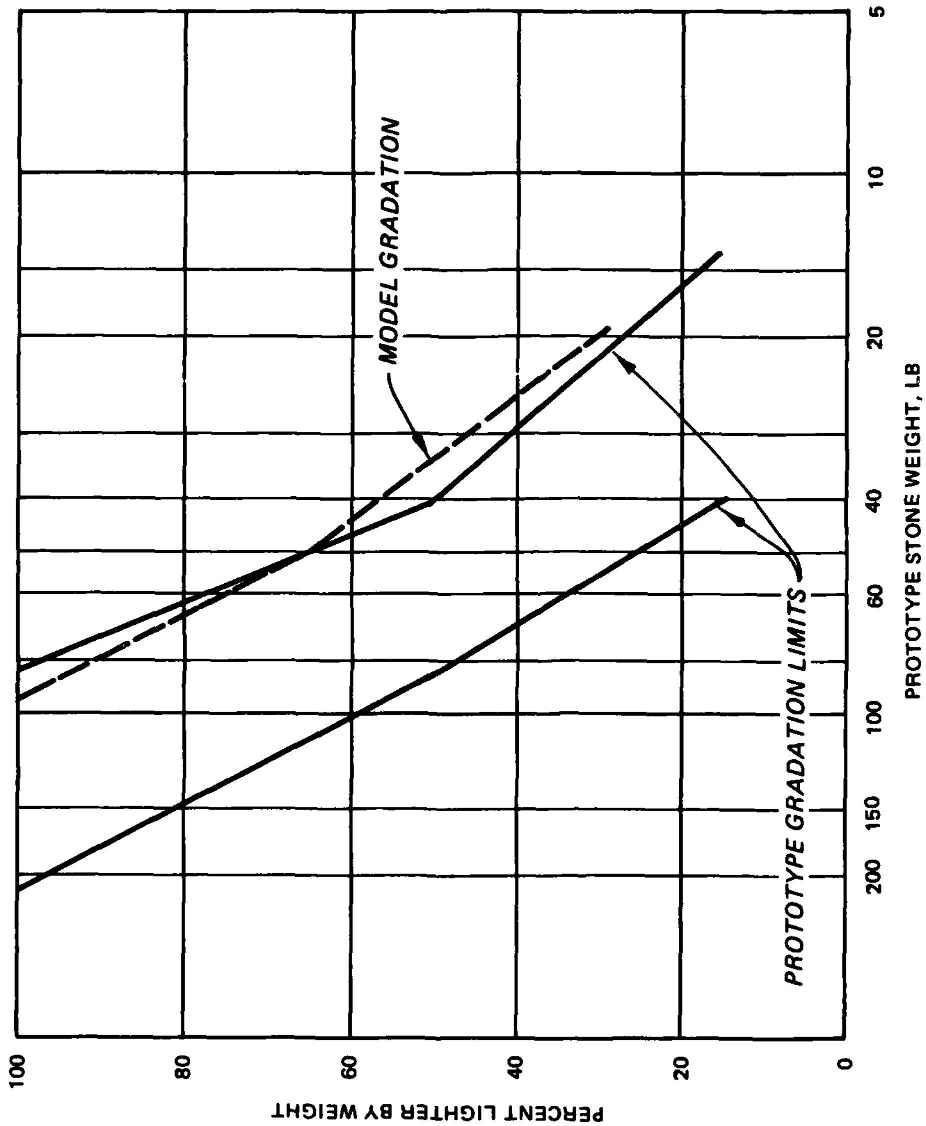
PLATE 10
(SHEET 6 OF 6)



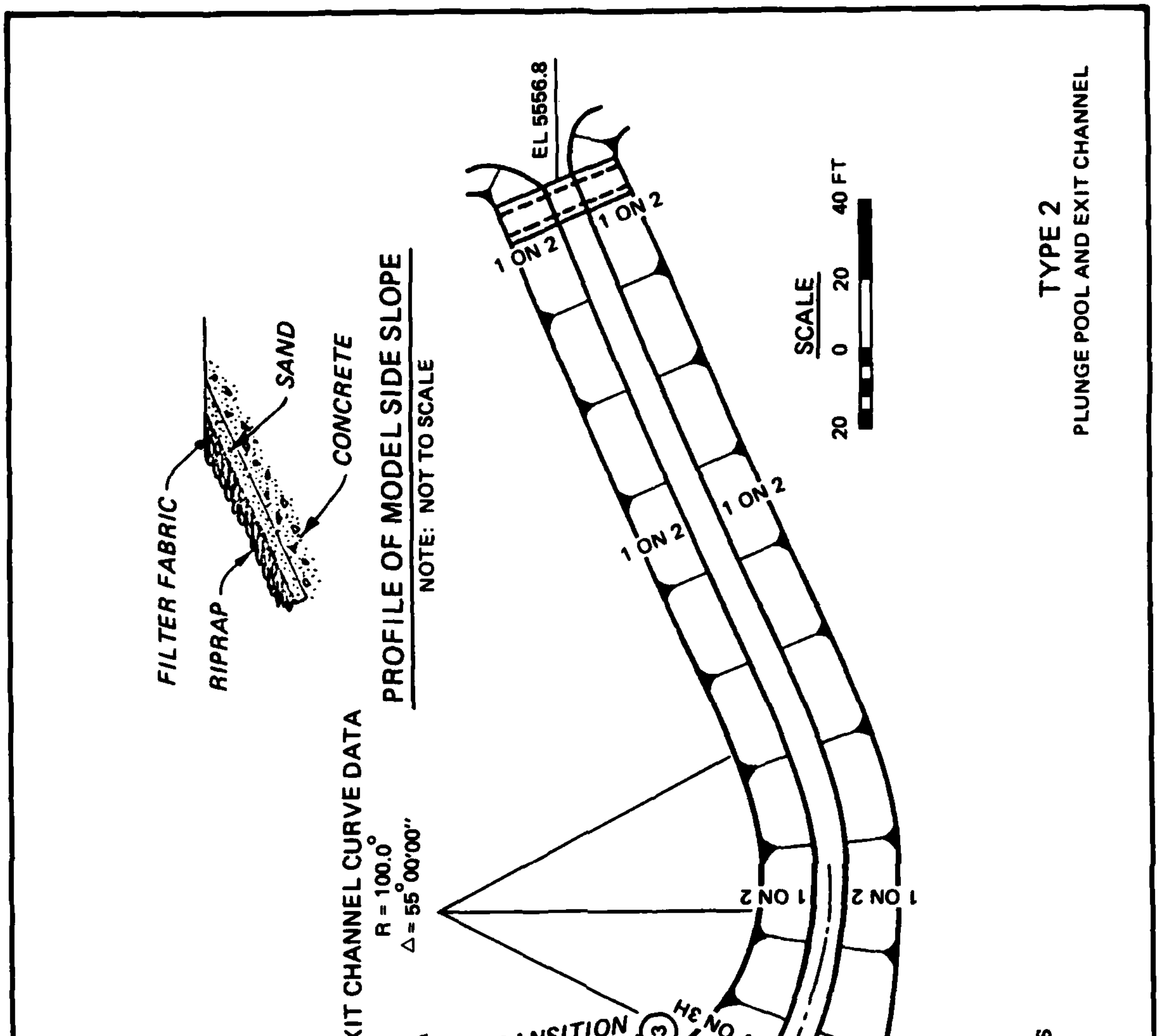
LOCATION OF WAVE HEIGHT MEASUREMENTS
ORIGINAL DESIGN



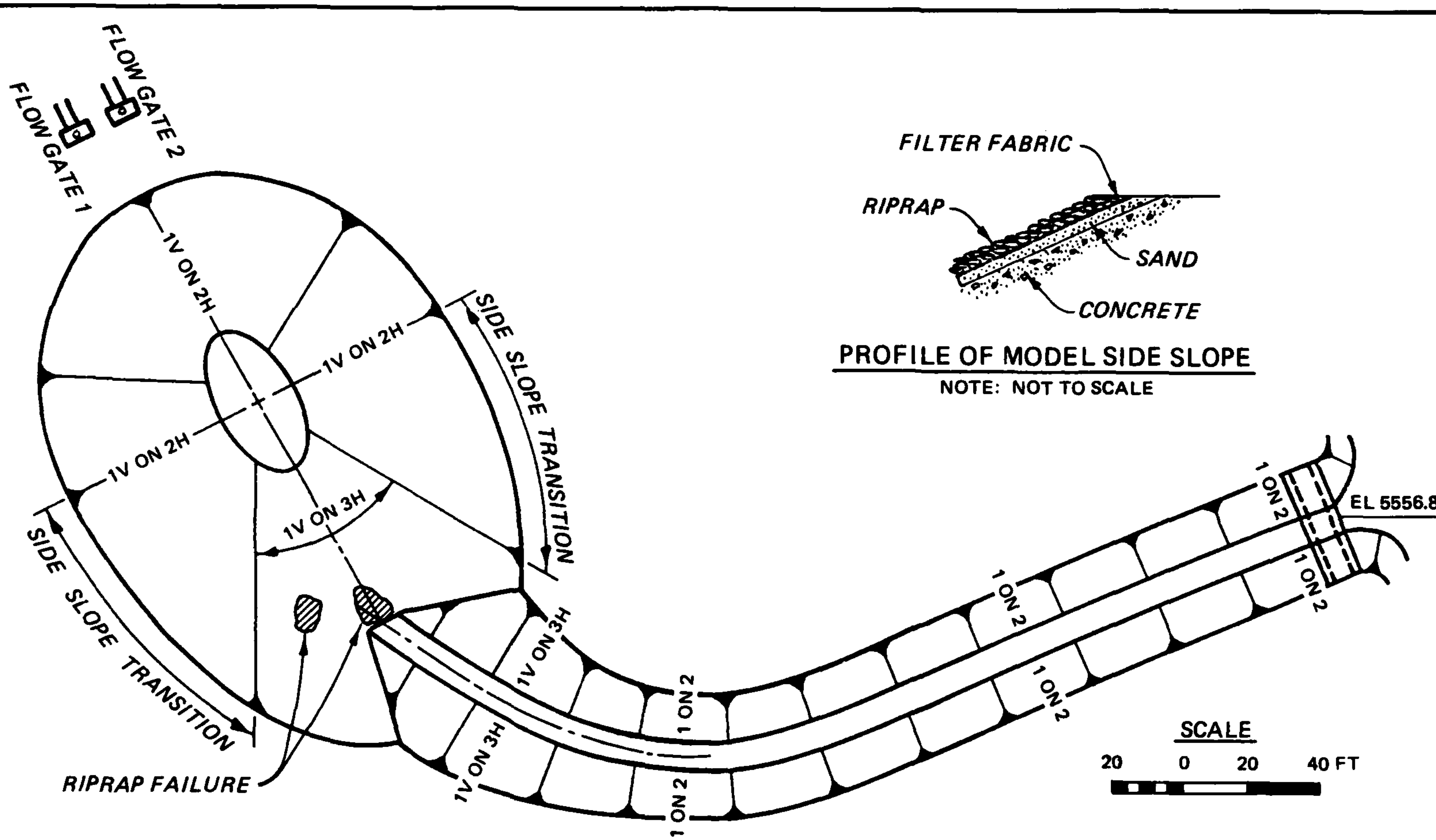
TYPE 2 RIPRAP DESIGN
TYPE 1 PLUNGE POOL



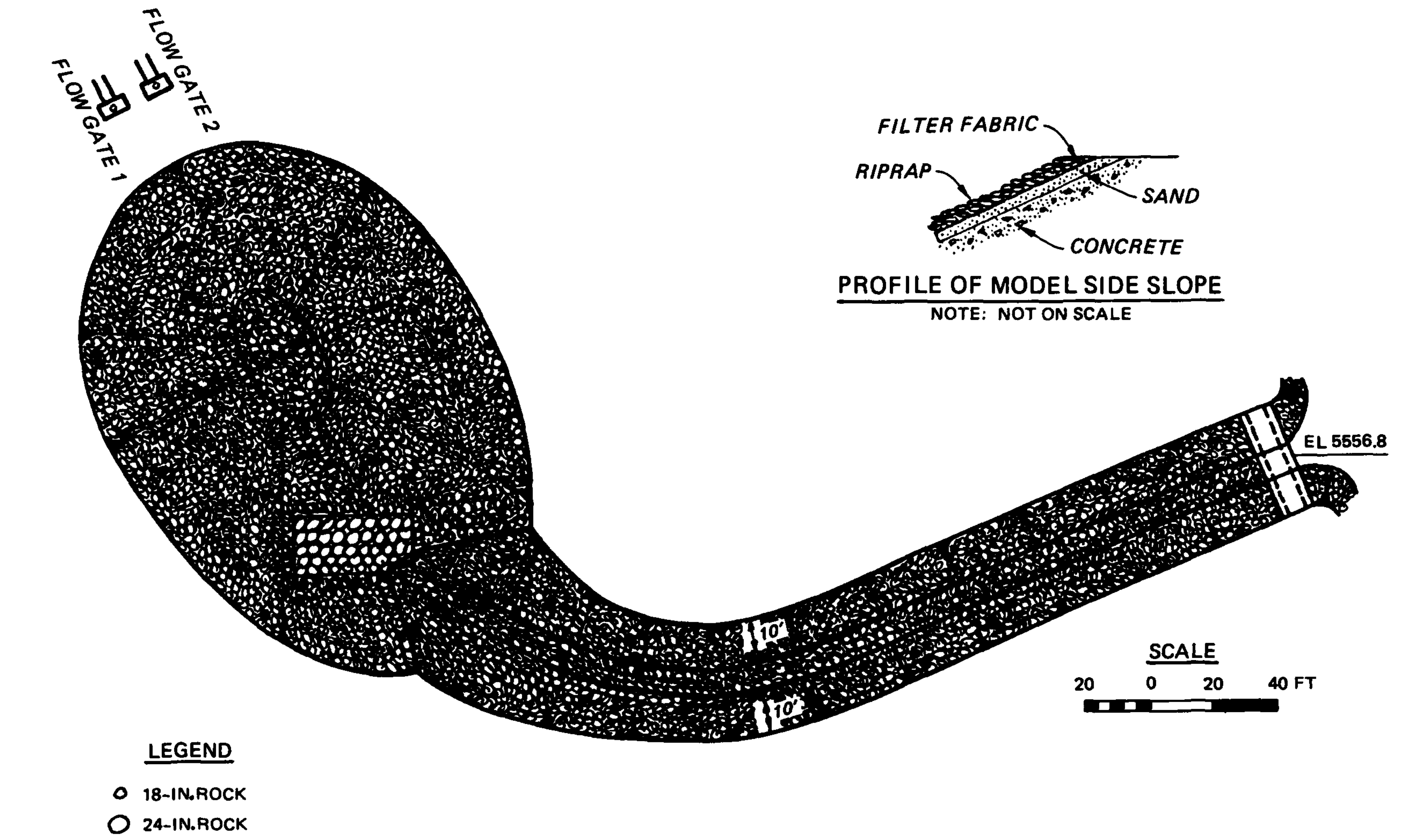
RIPRAP GRADATION
24 INCH



PROFILE OF MODEL SIDE SLOPE
NOTE: NOT TO SCALE
FILTER FABRIC
RIPRAP
SAND
CONCRETE
EXIT CHANNEL CURVE DATA
R = 100.0°
Δ = 55°00'00"
EL 5556.8
1 ON 2
1V ON 2H
1V ON 3H
SIDE SLOPE TRANSITION
FLOW GATE 1
FLOW GATE 2
SCALE
20 0 20 40 FT
TYPE 2
PLUNGE POOL AND EXIT CHANNEL
LEGEND
LOCATIONS OF WAVE HEIGHT MEASUREMENTS



RIPRAP FAILURE
TYPE 2 PLUNGE POOL AND EXIT CHANNEL
18-IN. RIPRAP DESIGN



TYPE 2 PLUNGE POOL AND EXIT CHANNEL DESIGN
TYPE 3 RIPRAP DESIGN

END
FILMED
6-89
DTIC